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THEORY OF AVIATION

PART I

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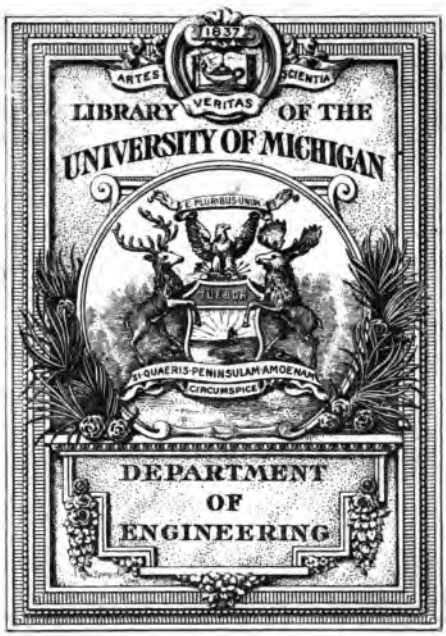
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THEORY OF AVIATION

PART I

INSTRUCTION PAPER

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THEORY OF AVIATION

PART I

EARLY DAYS OF AVIATION

As the derivation of the word indicates, *aviation* is employed to refer solely to the flying machine, or the heavier-than-air type, while under the general term *aeronautics* are included balloons, dirigibles, and similar apparatus, which depend upon the use of a lighter-than-air gas to give them the necessary lifting power.

Historical. *Cayley.* Man's ideas on the subject of flight are so old as to be legendary, but going back to Icarus or before him, would not be of even academic interest in the present connection. Like that of the dirigible, the actual history of the aeroplane began about a century ago, and just as Meusnier conceived the dirigible complete, embodying in his first designs all those important principles which have since proved to be indispensable, so did Sir George Cayley achieve a startling approach in his pioneering work to what present-day success has shown to be necessary for flight. In fact, Cayley's machine represents the true prototype of the modern aeroplane, combining features of both the Wright and Bleriot forms of construction. It had a single long, narrow plane of the proportions since demonstrated to be the most effective and was designed to be "drawn" by two screws run by chains from a single motor, the propellers being placed forward and one on either side, while stability, elevation, and steering were to be obtained through the medium of a tail.

More remarkable by far, however, was the knowledge of true principles displayed by its inventor; the proper calculation of the center of thrust and the fact that displacement takes place towards the front being known to Cayley. As in the case of the dirigible, it required almost a century to "rediscover" these principles and appreciate their value as Cayley described his machine in detail in *Nicholson's Journal* in 1809. He even dwelt on the subject that is now engrossing the foremost designers and inventors, automatic stability,

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and described a means of obtaining it. Unlike so many early investigators, Cayley did not end with planning a machine but actually built it. This first attempt was really the original glider, as it had no motor. The results obtained with it were so promising that a second machine was constructed and equipped with a small engine designed to be run by a tank of compressed air, and the form given the latter shows that the importance of wind resistance was fully appreciated. Unfortunately, Cayley's experiments terminated with the smashing of his machine in its trials.

Henson. That the results of his investigations were not entirely lost, however, is evident from Henson's machine of 1842, which was an even more astonishing anticipation of modern invention. Henson had not alone grasped the general principles but had also anticipated the actual construction of the aeroplanes that are performing such wonders in the air today. His machine was a monoplane and the wings with their ribbing and silk covering, stayed above and below to central posts placed in the main body, is almost identical with that of the French monoplane, the auxiliary trussing at the center of the planes constituting an arrangement employed on the Antoinette. In addition to the main planes, there was a hinged rear tail, and a rudder for vertical and horizontal control, and there was likewise a three-wheel chassis on which the machine was designed to run when on the ground. As a parallel to the Wright starting rail, Henson proposed to employ an inclined plane, the run-down which would give the initial impulse necessary to launch the machine in the air.

The main planes measured 30 by 150 feet, giving an area of 4,500 square feet, designed to be covered with silk or linen and to be perfectly rigid, although an arrangement of cords was devised for "reefing" or "setting" the coverings of the wings or planes, each of the latter being divided into three independent sections for this purpose. The tail was 50 feet long and this, as well as the rudder, was controlled by cords from the car. A small, vertical plane was placed at the center of the main planes to check lateral oscillation. All of the struts and braces were designed to present the minimum resistance to the air.

A light but very strong car was built directly under the central portion of the main plane and housed the power plant which consisted

of a two-cylinder, condensing steam engine, and water-tube boiler. The engine was capable of delivering about 20 horse-power and was designed to drive two six-bladed propellers, 20 feet in diameter. The condenser was practically the automobile radiator of many years later, a series of small, vertical tubes designed to be cooled by the air, so that only 20 gallons of water were necessary, and the total weight of the power plant, including its water supply, did not exceed 600 pounds. Every part of the machine was built to withstand stresses of a nature that only an expert engineer could foresee would be placed upon it. That Henson's machine would undoubtedly have met the fate that rewards every builder of an ambitious structure who has not the least idea of how to fly it, is a foregone conclusion.

Miscellaneous. This was probably responsible for the return to first principles that took place about 16 years later, when Le Bris demonstrated the first man-carrying kite in 1856. To obtain the necessary lifting force, the kite was towed by a wagon. Wenham, in 1866, made the first experiments in soaring or gliding. This was with a triplane and constituted the forerunner of the apparatus employed by Chanute, Archdeacon, and the Wrights 30 to 35 years later. Several years prior to Wenham's experiments, Nadar, D'Amecourt, and De la Handelle carried out an extended series of investigations, D'Amecourt building a working model of a steam helicopter —the first of its kind—in 1862. Enrico built another steam helicopter in 1878, weighing all told $6\frac{3}{4}$ pounds, which actually sustained itself in the air for a short time, while a year later Penaud constructed model aeroplanes on the lines of the present-day monoplane that actually soared, and Tatin's compressed-air machine suspended by a cord from a circular track showed its ability to fly independently of its support.

Langley. What may be regarded as the actual starting point of the investigation which ultimately demonstrated the possibility of human flight and the means of its attainment, dates from about 1888, when, by one of those curious coincidences which are frequently observed in the scientific world, several highly-qualified men simultaneously undertook the solution of the problem in different parts of the world. They were Professor Langley in America, Maxim in England, Lilienthal in Germany, and Hargrave in Australia. Pro-

fessor Langley first began his investigation of the laws of aeroplane flight in 1887. At that time, he built the now famous "whirling table," consisting of a horizontal rotating arm at the outer end of which were carried the planes and propellers to be tested. By means of ingenious automatic recording devices, the lifting power of different forms of planes, and of the same plane at different angles of incidence, was ascertained, and in the same way the thrust of various types of propellers was recorded.

The complete results of these investigations were incorporated in a work entitled "Experiments in Aerodynamics," first published in 1891. Among the important principles established was that of the size of the supporting surface as governed by its speed of travel. That the area of the necessary supporting surface in an aeroplane varies inversely as the square of the velocity, which means that if a biplane requires 500 square feet of supporting surface at 40 miles an hour, it would need only 222 feet at 60 miles an hour, while 80 square feet would suffice for a speed of 100 miles an hour. Langley explained that this was due to the fact that at the higher speeds, the planes passed so rapidly on to new and undisturbed bodies of air, that there was not sufficient time for them to overcome the inertia of the air, an analogy to this being found in the skater on thin ice, who does not remain sufficiently long at any one point to break through. Of all the scientists who undertook the solution of the problem, Langley's work was undoubtedly the most thorough, and it is referred to more at length later, as most of his important results were achieved a few years later.

Maxim. Maxim, in 1894, undertook the construction of a huge biplane, though it bore no resemblance to any of the machines of this type of the present day. Fully $100,000 was expended on the project and the latter affords an excellent example of the wisdom of the policy adopted by the Wright Brothers at the inception of their first serious work. They realized that the most necessary thing was to learn how to fly—in other words, how to control an aeroplane before attempting to build one. Maxim was also aware of the importance of this, as evidenced by the fact that all his early experiments were made with the machine captive. It was fitted with wheels running on wood rails and supplementary guard rails were designed to prevent it from leaving the earth. The machine

was so powerful, however, that it tore away from the latter and was smashed in alighting.

Some idea of the size of the Maxim machine may be conceived from its supporting area of 5,400 square feet, made up of a central rectangular plane directly over the operating platform; forward, aft, and two side planes at the same level; and two side planes at the level of the platform. This was the original design, subsequently reduced to 4,000 square feet by the elimination of the forward and side planes, a great reduction in area of the central plane and a change in its shape to a rectangle with its long side forward, and the addition of a second smaller superimposed plane, making it practically a biplane with the machinery and operating platform suspended some distance below it. The total lift of the planes was 10,000 pounds.

The internal combustion motor not having been developed at that time, steam was employed and the power plant was of a most ingenious order, replete with novel automatic devices. The boiler was of the water-tube type, the light copper tubes being assembled in the form of a triangle, with a nest of additional tubes in serpentine form in the opening of the latter, giving a total heating surface of about 800 square feet, with a "firebox" surface of 30 square feet. Its weight with a feedwater heater and gasoline furnace was 1,200 pounds, 200 pounds of this consisting of the supply of water itself. The gasoline fuel was heated in a special receptacle and was delivered through 7,650 fine jets at a pressure of 50 pounds to the square inch. A number of ingenious devices were employed to regulate the supply of fuel as well as its pre-heating before burning. The boiler was designed to supply steam at a pressure of 360 pounds to a compound, condensing engine giving 360 horse-power.

This power drove two propellers 17 feet 10 inches in diameter by 16 feet pitch at 375 r.p.m. The screw thrust before starting reached as high as 2,100 pounds, Mr. Maxim having calculated that of the total power, 150 horse-power would be wasted in slip, 130 horse-power expended in actual lift on the angle of the planes, and 80 horse-power utilized in driving. The engine cylinders, frame, and rods were all of sheet steel so that its total weight was only 600 pounds, setting a new limit at that time of 2 pounds per horse-power. A safety device led the high-pressure steam into the low-pressure

cylinders in case the boiler pressure became too high, this increasing the output to 400 horse-power. It was truly a case of Frankenstein being overpowered by the monster he himself had created, as shown by the subsequent wrecking of the machine. Even in the light of present-day knowledge, few aviators would care to attempt the handling of such a huge contrivance. When it is borne in mind that the cost of the best of modern aeroplanes does not exceed $8,000, it seems a pity that such a sum should have been expended at a time when practical results would have done so much for the development of the art.

Langley's Experiments. Two years later, or in 1896, Langley made his now historic experiments with steam-driven models, but before referring to these it will be of interest to note for how much of our present knowledge his early investigations were responsible. To give these at length from his own works would involve more space than is available, so that the following is excerpted from an address made by Prof. Alexander Graham Bell, the inventor of the telephone, on the occasion of the presentation of the Langley medal to the Wright Brothers, February 10, 1910. The indebtedness of the latter to Langley's work is fittingly acknowledged by them in their own story of their experiments, which is given on page 9.

Langley's experiments in aerodynamics gave to physicists, perhaps for the first time, firm ground on which to stand as to the long-disputed questions of air resistance and reactions. Chanute says:

(1) They established a more reliable coefficient for rectangular pressures than that of Smeaton.

(2) They proved that upon inclined planes the air pressures were really normal to the surface.

(3) They disproved the Newtonian law that the normal pressure varied as the square of the angle of incidence on inclined planes.

(4) They showed that the empirical formula of Duchemin which had been proposed in 1836 and ignored for fifty years, was approximately correct.

(5) That the position of the center of pressure varied with the angle of inclination, and that on planes its movements approximately followed the law formulated by Joessel.

(6) That oblong planes, presented with their longest dimension in the direction of motion, were more effective for support than when presented with their narrower side.

(7) That planes might be superposed without loss of supporting power if spaced apart certain distances which varied with the speed.

(8) That thin planes consumed less power for support at high speeds than at low speeds.

The paradoxical result obtained by Langley—that it takes less power to support a plane at high speed than at low—opens up enormous possibilities for the aerodrome of the future. It results, as Chanute has pointed out, from the fact that the higher the speed, the less need be the angle of inclination to sustain a given weight, and the less, therefore, the horizontal component of the air pressure.

It is true, however, only of the plane itself, and not of the struts and frame work that go to make up the rest of the flying machine.* In order,

Fig. 1. Langley's Aerodrome Ready for a Flight

therefore, to take full advantage of Langley's law, those portions of the machine that offer head resistance alone, without contributing anything to the support of the machine in the air, should be reduced to a minimum.

After laying the foundations of a science, Langley proceeded to reduce his theories to practice. Between 1891 and 1895, he built four models, one driven by carbonic-acid gas and three by steam. On May 6, 1896, his aerodrome No. 5 was tried on the Potomac River near Washington. I was a witness of this experiment, and secured photographs of the machine in the air, which have been widely published.

This aerodrome carried a steam engine and had a spread of wing of from 12 to 14 feet. It was shot into the air from the roof of a house boat anchored

*In this is found the superiority in speed of the monoplane over the biplane.—Ed.

in a quiet bay at Quantico. It made a beautiful flight of about 3,000 feet, considerably over half a mile. It was indeed a most inspiring spectacle to see a steam engine in the air, flying like a bird. The equilibrium seemed to be perfect, though there was no man on board to control and guide the machine. I witnessed two flights of this aerodrome the same day and came to the conclusion that the possibility of flight by heavier-than-air machines had been fully demonstrated. The world took the same view and the progress of practical aerodromics was immensely stimulated by the experiments.

Langley afterward constructed a number of other aerodrome models which were flown with equal success, and he then felt that he had brought his researches to a conclusion and desired to leave to others the task of bringing the experiments to the man-carrying stage. Later, however, encouraged by the appreciation of the War Department, which recognized in the Langley aerodrome a possible new engine of war, and stimulated by an appropriation of $50,000, he constructed a full-sized machine to carry a man.

Two attempts were made, with Charles Manley as the aviator, to shoot the machine into the air from the top of a house boat, Fig. 1, but on each occasion it caught on the launching ways and was precipitated into the water. The public, not knowing the cause, received the impression that the machine itself was a failure.*

This conclusion was not warranted by the facts, and to me, and to others who examined the apparatus, it seemed to be a perfectly good flying machine, excellently constructed and the fruit of years of labor. It was simply never launched into the air, and so has never had an opportunity of showing what it could do. Who can say what a third trial might have demonstrated? The general ridicule, however, with which the first two trials were greeted, prevented any further appropriation.†

Langley's faith never wavered, but he never saw a man-carrying aerodrome in the air. He was humiliated by the ridicule which met his efforts and never recovered from his disappointment, which hastened his death. His greatest achievements in practical aerodynamics consisted in the successful construction of power-driven models which actually flew.‡ With their construction, he thought he had finished his work, and in 1901, in announcing the supposed conclusion of his labors, he said:

"I have brought to a close the portion of the work which seemed to be specially mine, the demonstration of the practicability of mechanical flight,

*The impression was fostered by the press for the reason that Langley originally would not permit the presence of any reporters. He later consented, but the numerous delays involved in preparing the machine, together with the fact that little information was volunteered and the gentlemen in question were utterly incompetent to obtain any first hand, engendered a hostile attitude on their part. This was aggravated by tedious hours of waiting around in skiffs under the blazing sun for something in the nature of "copy" to happen, so that they were only too ready to seize upon an opportunity to ridicule. In the confusion attendant upon Manley's second spill in the water, no attention was paid to the machine at first, and it was rescued by the crew of a tugboat. Their ignorance of its construction and bungling efforts resulted in wrecking it badly, which was ascribed by the press to its fall in the water, which had in fact not damaged it particularly. Hence, the widespread report that it was an utter failure. —Ed.

†The machine has been preserved and there is a movement on foot to put it in commission and try it.—Ed.

‡These machines did not wreck themselves as had Ader's machine in France, and Maxim's in England.—Ed.

and for the next stage, which is the practical and commercial development of the idea, it is probable the world may look to others."

He was right, and the others have appeared. The aerodrome has reached the practical and commercial stage; and chief among those who are developing this field are the brothers, Orville and Wilbur Wright. They are eminently deserving of the highest honor from us for their great achievements.

Wright Brothers' Experiments. So many and varied stories have appeared of what the Wright Brothers, Fig. 2, have done and how they did it—many of them largely fiction and others so garbled as to be scarcely recognizable by those about whom they were written —that it is thought advisable to reproduce here *verbatim* their own account of their exploits, as written by them and published in the *Century*, December, 1908. This is the only true and concise report.

Fig. 2. Orville and Wilbur Wright

"Our personal interest in the subject of aerial navigation dates from our childhood days. Late in the autumn of 1878, our father came into the house one evening with some object partly concealed in his hands, and before we could see what it was, he tossed it into the air. Instead of falling to the floor, as we expected, it flew across the room until it struck the ceiling, where it fluttered awhile, and finally sank to the floor. It was a little toy, known to scientists as a helicopter, but which we, with supreme disregard for science, at once dubbed a 'bat.' It was a light frame of cork and bamboo, covered with paper, which formed two screws, driven in opposite directions by rubber bands under torsion. A toy so delicate lasted only a short time in the hands of small boys, but its memory was abiding.

"Several years later, we began building these helicopters for ourselves, making each one larger than the preceding. But, to our

astonishment, we found that the larger the 'bat' the less it flew. We did not know that one machine having only twice the linear dimensions of another would require eight times the power. We finally became discouraged and returned to kite-flying, a sport to which we had devoted so much attention that we were regarded as experts. But as we became older, we had to give up this fascinating sport as unbecoming to boys of our ages.

"It was not until the sad news of the death of Lilienthal reached America, in 1896, that we again gave more than passing attention to the subject of flying. We then studied with great interest Cha-

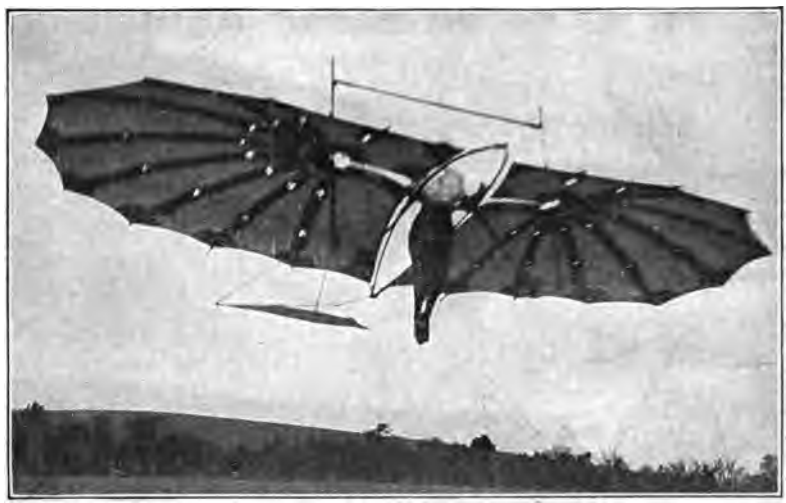

Fig. 3. Lilienthal's Gliding Apparatus

nute's 'Progress in Flying Machines,' Langley's 'Experiments in Aerodynamics,' the Aeronautical Annuals of 1895, 1896, and 1897, and several pamphlets published by the Smithsonian Institution, especially articles by Lilienthal and extracts from Mouillard's 'Empire of the Air.' The larger works gave us a good understanding of the nature of the problem of flying, and the difficulties in past attempts to solve it, while Mouillard and Lilienthal, the great missionaries of the flying cause, infected us with their own unquenchable enthusiasm and transformed idle curiosity into the active zeal of workers.

"In the field of aviation, there were two schools. The *first*, represented by such men as Professor Langley and Sir Hiram Maxim, gave chief attention to power flight; the *second*, represented by Lilienthal, Fig. 3, Mouillard, and Chanute, to soaring flight. Our sympathies were with the latter school, partly from impatience at the wasteful extravagance of mounting delicate and costly machinery on wings which no one knew how to manage, and partly, no doubt, from the extraordinary charm and enthusiasm with which the apostles of soaring flight set forth the beauties of sailing through the air on fixed wings, deriving the motive power from the wind itself.

Balancing Methods. "The balancing of a flyer may seem, at first thought, to be a very simple matter, yet almost every experimenter had found this to be the one point which he could not master. Many different methods were tried. Some experimenters placed the center of gravity far below the wings, in the belief that the weight would naturally seek to remain at the lowest point. It was true, that, like the pendulum, it tended to seek the lowest point; but also, like the pendulum, it tended to oscillate in a manner destructive of all stability. A more satisfactory system, especially for lateral balance, was that of arranging the wings in the shape of a broad **V** to form a dihedral angle, with the center low and the wing tips elevated. In theory, this was an automatic system, but in practice it had two serious defects: *First*, it tended to keep the machine oscillating; and *second*, its usefulness was restricted to calm air.

"In a slightly modified form, the same system was applied to the fore-and-aft balance. The main aeroplane was set at a positive angle, and a horizontal tail at a negative angle, while the center of gravity was placed far forward. As in the case of lateral control, there was a tendency to constant undulation, and the very forces which caused a restoration of balance in calms, caused a disturbance of the balance in winds. Notwithstanding the known limitations of this principle, it had been embodied in almost every prominent flying machine which had been built.

"After considering the practical effect of the dihedral principle we reached the conclusion that a flyer founded upon it might be of interest from a scientific point of view, but could be of no value in a practical way. We therefore resolved to try a fundamentally different principle. We would arrange the machine so that it would

tend to right itself. We would make it as inert as possible to the effects of change of direction or speed, and thus reduce the effects of wind gusts to a minimum. We would do this in the fore-and-aft stability by giving the aeroplanes a peculiar shape; and, in the lateral balance, by arching the surfaces from tip to tip, just the reverse of what our predecessors had done. Then by some suitable contrivance actuated by the operator, forces should be brought into play to regulate the balance.

Working Its Planes. "Lilienthal and Chanute had guided and balanced their machines by shifting the weight of the operator's

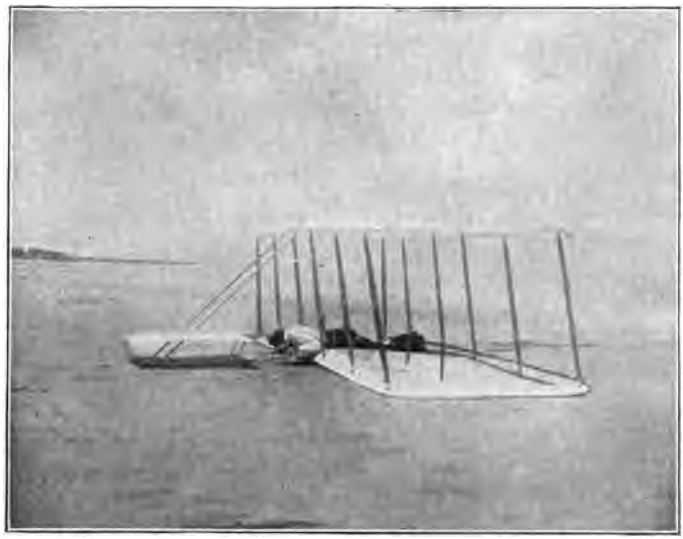

Fig. 4. An Early Wright Glider Showing Horizontal Front Rudder

body. But this method seemed to us incapable of expansion to meet large conditions, because the weight to be moved and the distance of possible motion were limited, while the disturbing forces steadily increased, both with wing area and wind velocity. In order to meet the needs of large machines, we wished to employ some system whereby the operator could vary at will the inclination of the different parts of the wings, and thus obtain from the wind, forces to restore the balance, which the wind itself had disturbed. This could easily be done by using wings capable of being warped, and by supple-

mentary adjustable surfaces in the shape of rudders. As the forces obtainable for control would necessarily increase in the same ratio as the disturbing forces, the method seemed capable of expansion to an almost unlimited extent. A happy device was discovered whereby the apparently rigid system of superposed surfaces, invented by Wenham and improved by Stringfellow and Chanute, could be warped in a most unexpected way, so that the aeroplanes could be presented on the right and left sides at different angles to the wind. This, with an adjustable, horizontal front rudder, formed the main feature of our first glider, Fig. 4.

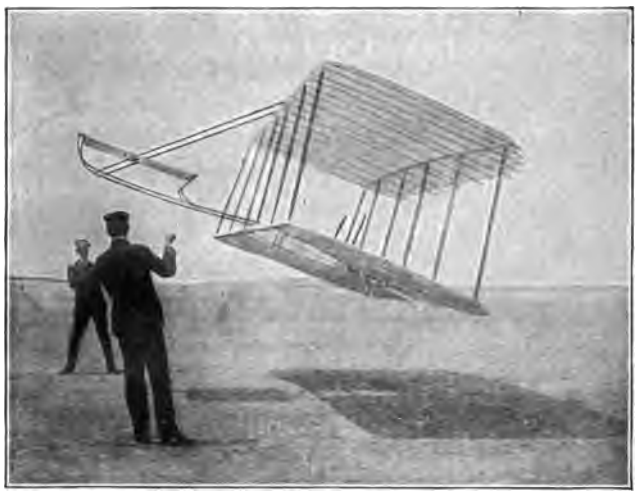

Fig. 5. Flying a Glider as a Kite to Study its Action

"The period from 1885 to 1900 was one of unexampled activity in aeronautics, and for a time there was high hope that the age of flying was at hand. But Maxim, after spending $100,000, abandoned the work; the Ader machine, built at the expense of the French government, was a failure; Lilienthal and Pilcher were killed in experiments; and Chanute and many others, from one cause or another, had relaxed their efforts, though it subsequently became known that Professor Langley was still secretly at work on a machine for the United States government. The public, discouraged by the failures and tragedies just witnessed, considered flight beyond the

reach of man, and classed its adherents with the would-be inventors of perpetual motion.

"We began our active experiments at the close of this period, in October, 1900, at Kitty Hawk, North Carolina. Our machine was designed to be flown as a kite, with a man on board, in winds from 15 to 20 miles an hour. But, upon trial, it was found that much stronger winds were required to lift it. Suitable winds not being plentiful, we found it necessary, in order to test the new balancing system, to fly the machine as a kite without a man aboard, operating the levers through chords from the ground, Fig. 5. This

Fig. 6. Testing the Balance of a Glider with a Man Aboard

did not give the practice anticipated but it inspired confidence in the new system of balance.

"In the summer of 1901, we became personally acquainted with Chanute. When he learned that we were interested in flying as a sport, and not with any expectation of recovering the money we were expending upon it, he gave us much encouragement. At our invitation, he spent several weeks with us at our camp at Kill Devil Hill, four miles south of Kitty Hawk, during our experiments of that and two succeeding years. He also witnessed one flight of the power-driven machine near Dayton, Ohio, in October, 1904.

"The machine of 1901 was built with the shape of surface used by Lilienthal, curved from front to rear like the segment of a parabola,

with a curvature of one-twelfth the depth of its chord; to make sure that it would have sufficient lifting capacity when flown as a kite in 15- or 20-mile winds, we increased the area from 165 square feet, used in 1900, to 308 square feet—a size much larger than Lilienthal, Pilcher, or Chanute had deemed safe. Upon trial, however, the lifting capacity again fell very far short of calculation, so that the idea of securing practice while flying as a kite, had to be abandoned. Chanute, who witnessed the experiments, told us that the trouble was not due to poor construction of the machine. We

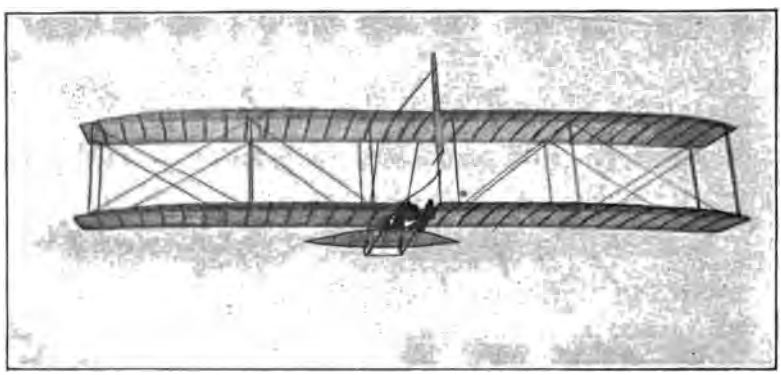

Fig. 7. Glider with Vertical Rear Rudder

saw only one other explanation—that the tables of air pressures in general use were incorrect.

Gliding Experiments. "We then turned to gliding—coasting down hill on the air—as the only method of getting the desired practice in balancing a machine, Fig. 6. After a few minutes practice we were able to make glides of over 300 feet, and in a few days were safely operating in 27-mile winds. The gliding flights were all made against the wind. The difficulty in high winds is in maintaining balance, not in traveling against the wind. In these experiments we met with several unexpected phenomena. We found that, contrary to the teachings of the books, the center of pressure on a curved surface traveled backward when the surface was inclined, at small angles, more and more edgewise to the wind. We also discovered that in free flight, when the wing on one side of the machine was presented to the wind at a greater angle than the one on the

other side, the wing with the greater angle descended, and the machine turned in a direction just the reverse of what we were led to expect when flying the machine as a kite. The larger angle gave more resistance to forward motion, and reduced the speed of the wing on that side. The decrease in speed more than counterbalanced the effect of the larger angle. The addition of a fixed vertical vane, Fig. 7, in the rear increased the trouble and made the machine absolutely dangerous. It was some time before a remedy was discovered. This consisted of movable wings working in conjunction with the twisting of the wings. The details of this arrangement are given in our patent specifications, published several years ago.*

Verification of Pressure Constants. "The experiments of 1901 were far from encouraging. Although Chanute assured us that both in control and weight carried per horse-power, the results obtained were better than those of any of our predecessors, yet we saw that the calculations on which all flying machines had been based were unreliable, and that every experimenter was simply groping in the dark. Having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, till finally, after two years of experiment, we cast it all aside and decided to rely entirely upon our own investigations. Truth and error were everywhere so intimately mixed as to be indistinguishable. Nevertheless, the time expended in the preliminary study of books was not misspent, for they gave us a good general understanding of the subject and enabled us at the outset to avoid effort in many directions in which results would have been hopeless.

"The standard for measurements of wind pressures is the force produced by a current of air of 1-mile-per-hour velocity striking against a plane of 1 square foot area. The practical difficulty of obtaining an exact measurement of this force has been great. The measurements by different recognized authorities vary 50 per cent. When this simplest of measurements presents so great difficulties, what shall be said of the troubles encountered by those who attempt to find the pressure at each angle as the plane is inclined more and more edgewise to the wind? In the eighteenth century, the French Academy prepared tables giving such information, and at a later date the Aeronautical Society of Great Britain made similar experiments.

*See pages 65 and 75, Aeronautical Practice, Part II.

Many persons likewise published measurements and formulas; but the results were so discordant that Professor Langley undertook a new series of measurements, the results of which form the basis of his celebrated work 'Experiments in Aerodynamics.' Yet a critical examination of the data upon which he based his conclusions as to pressures at small angles shows results so various as to make many of his conclusions little better than guesswork.

"To work intelligently, one needs to know the effects of a multitude of variations that could be incorporated in the surfaces of flying machines. The pressures on squares are different from those on rectangles, circles, triangles, or ellipses; arched surfaces differ from planes, and vary among themselves according to the depth of curvature; true arcs differ from parabolas, and the latter differ among themselves; thick surfaces differ from thin, and surfaces thicker in one place than another vary in pressure when the positions of maximum thickness are different; some surfaces are most efficient at one angle, others at other angles. The shape of the edge also makes a difference, so that thousands of combinations are possible in so simple a thing as a wing.

"We had taken up aeronautics merely as a sport. We reluctantly entered on the scientific side of it. But we soon found the work so fascinating that we were drawn into it deeper and deeper. Two testing machines were built, which we believed would avoid the errors to which the measurements of others had been subject. After making preliminary measurements on a great number of surfaces to secure a general understanding of the subject, we began systematic measurements of standard surfaces so varied in design as to bring out the underlying causes of differences noted in their pressures. Measurements were tabulated on nearly fifty of these at all angles from zero to 45 degrees, at intervals of $2\frac{1}{2}$ degrees. Measurements were also secured showing the effects on each other when surfaces are superposed, or when they follow one another.

"Some strange results were obtained. One surface, with a heavy roll at the front edge, showed the same lift for al angles from $7\frac{1}{2}$ to 45 degrees. A square plane, contrary to the measurements of all our predecessors, gave a greater pressure at 30 degrees than at 45 degrees. This seemed so anomalous that we were almost ready to doubt our own measurements when a simple test was suggested. A

weather vane with two planes attached to the pointer at an angle of 80 degrees with each other was made. According to our tables, such a vane would be in unstable equilibrium when pointing directly into the wind; for if, by chance, the wind should happen to strike one plane at 39 degrees and the other at 41 degrees, the plane with the smaller angle would have the greater pressure, and the pointer would be turned still further out of the course of the wind until the two vanes again secured equal pressures, which would be approximately at 30 and 50 degrees. But the vane performed in this very manner. Further corroboration of the tables was obtained in the experiments with a new glider at Kill Devil Hill the next season.

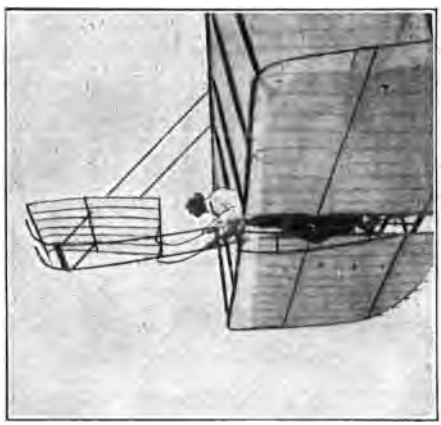

Fig. 8. Gliding Flight, Showing Prone Position of Operator

"In September and October, 1902, nearly 1,000 gliding flights were made, several of which covered distances of over 600 feet (all made with the operator lying prone as shown in Fig. 8). Some glides against a wind of 36 miles an hour gave proof of the effectiveness of the devices for control. With this machine, in the autumn of 1903, we made a number of flights in which we remained in the air for over a minute, often soaring for a considerable time in one spot without any descent at all. Little wonder that our unscientific assistant should think the only thing needed to keep it in the air indefinitely would be a coat of feathers to make it light!

"With accurate data for making calculations, and a system of balance effective in winds as well as in calms, we were now in a position, we thought, to build a successful power flyer. The first designs provided for a total weight of 600 pounds, including the operator and an 8-horse-power motor. But upon completion, the motor gave more power than had been estimated, and this allowed 150 pounds for strengthening the wings and other parts.

Propeller Design. "Our tables made the designing of the wings an easy matter; and as screw propellers are merely wings traveling in a spiral course, we anticipated no trouble from this source. We had thought of getting the theory of the screw propeller from the marine engineers, and then, by applying our tables of air pressures to their formulas, of designing air propellers. But so far as we could learn, the marine engineers possessed only empirical formulas, and the exact action of the screw propeller, after a century of use, was still very obscure. As we were not in a position to undertake a long series of practical experiments to discover a propeller suitable for our machine, it seemed necessary to obtain such a thorough understanding of the theory of its reactions as would enable us to design them from calculation alone. What at first seemed a simple problem, became more complex the longer we studied it. With the machine moving forward, the air flying backward, the propellers turning sidewise, and nothing standing still, it seemed impossible to find a starting point from which to trace the various simultaneous reactions. Contemplation of it was confusing. After long arguments, we often found ourselves in the ludicrous position of each having been converted to the other's side, with no more agreement than when the discussion began.

"It was not until several months had passed, and every phase of the problem had been threshed over and over, that the various reactions began to untangle themselves. When once a clear understanding had been obtained there was no difficulty in designing suitable propellers, with proper diameter, pitch, and area of blade, to meet the requirements of the flyer. High efficiency in a propeller is not dependent upon any particular or peculiar shape, and there is no such thing as a *best* screw. A propeller giving a high dynamic efficiency when used upon one machine, may be almost worthless when used upon another. The propeller should in every case be designed to meet the particular conditions of the machine to which it is to be applied. Our first propellers, built entirely from calculation, gave in useful work 66 per cent of the power expended. This was about one-third more than had been secured by Maxim or Langley.

First Power Flight. "The first flights with the power machine were made on the 17th of December, 1903. Only five persons beside ourselves were present. These were Messrs. John T. Daniels, W. S.

Dough, and A. D. Etheridge of the Kill Devil life saving station; W. C. Brinkley of Manteo; and John Ward of Naghead. Although a general invitation had been extended to the people living within 5 or 6 miles, not many were willing to face the rigors of a cold December wind in order to see, as they no doubt thought, another flying machine *not fly*. The *first* flight lasted only 12 seconds, a flight very modest compared with that of birds, but it was, nevertheless, the

Fig. 9. One of the First Power Flights of the Wright Biplane

first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in free flight, had sailed forward on a level course without reduction in speed, and had finally landed without being wrecked. The *second* and *third* flights were a little longer, and the *fourth* lasted 59 seconds, covering a distance of 853 feet over the ground against a 20-mile wind, Fig. 9.

"After the last flight, the machine was carried back to camp and set down in what was thought to be a safe place. But a few minutes later, while we were engaged in conversation about the

flights, a sudden gust of wind struck the machine and started to turn it over. All made a rush to stop it but we were too late. Daniels, a giant in stature and strength, was lifted off his feet and, falling inside between the surfaces, was shaken about like a rattle in a box while the machine rolled over and over. He finally fell out upon the sand with nothing worse than painful bruises, but the damage to the machine caused a discontinuancce of the experiments.

"In the spring of 1904, through the kindness of Torrence Huffman of Dayton, Ohio, we were permitted to erect a shed and continue experiments, on what is known as the Huffman prairie, at Simms Station, eight miles from Dayton. The new machine was heavier and stronger but similar to the one flown at Kill Devil Hill. When it was ready for its first trial, every newspaper in Dayton was notified, and about a dozen representatives of the press were present. Our only request was that no pictures be taken and that the reports be unsensational, so as not to attract crowds to our experiment grounds. There were probably 40 persons altogether on the ground. When preparations were completed, a wind of only 3 or 4 miles an hour was blowing—insufficient for starting on so short a track—but since so many had come a long way to see the machine in action, an attempt was made. To add to the other difficulty, the engine refused to work properly. The machine, after running the length of the track, slid off without rising into the air at all. Several of the newspaper men returned the next day but were again disappointed. The engine again performed badly and after a glide of only 60 feet, the machine came to the ground. Further trial was postponed until the engine could be put in better condition. The reporters had now, no doubt, lost confidence in the machine, though their reports, in kindness, concealed it. Later, when they heard that we were making flights of several minutes' duration, knowing that longer flights had been made in airships, and not knowing any essential difference between airships and flying machines, they were but little interested.

"We had not been flying long in 1904 before we found that the problem of equilibrium had not as yet been entirely solved. Sometimes, in making a circle, the machine would turn over edgewise in spite of anything the operator could do, although, under the same conditions in ordinary straight flight, it could have been righted in an instant. In one flight, in 1905, while circling around a honey

locust tree at a height of about 50 feet, the machine suddenly began to turn up on one wing and took a course toward the tree. The operator, not relishing the idea of landing in a thorn tree, attempted to reach the ground. The left wing, however, struck the tree at a height of 10 or 12 feet from the ground and carried away several branches; but the flight, which had already covered a distance of 6 miles, was continued to the starting point.

"The causes of these troubles, too technical for explanation here, were not entirely overcome till the end of September, 1905. The flights then rapidly increased in length, till experiments were dis-

Fig. 10. Preparing the Machine for the Start

continued, after the 5th of October, on account of the number of people attracted to the field. Although made on a ground open on every side, and bordered on two sides by much traveled thoroughfares, with electric cars passing every hour, and seen by all people living in the neighborhood for miles around, and by several hundred others, yet these flights have been made by some newspapers the subject of a great 'mystery.'

"A practical design having been finally realized, we spent the years 1906 and 1907 in constructing new machines and in business negotiations. It was not until May of this year (1908) that experiments (discontinued in October, 1905) were resumed at Kill Devil

Hill, North Carolina. The recent flights were made to test the ability of our machine to meet the requirements of a contract with the United States government to furnish a flyer capable of carrying two men and sufficient fuel and supplies for a flight of 125 miles, with a speed of 40 miles an hour. The machine used in these tests was the same one with which the flights were made at Simms Station in 1905, though several changes had been made to meet present requirements. The operator assumed a sitting position, instead of lying prone as in 1905, and a seat was added for a passenger. A larger motor was

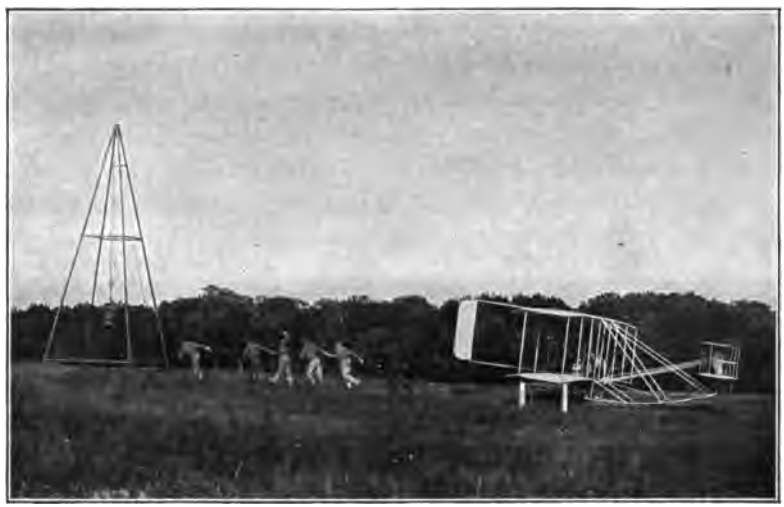

Fig. 11. Starting Device Used with the Early Wright Machines

installed, and radiators and gasoline reservoirs of larger capacity replaced those previously used. No attempt was made to make high or long flights.

Management of an Aeroplane. "In order to show the general reader the way in which the machine operates, let us fancy ourselves ready for the start, Fig. 10. The machine is placed upon a single rail track facing the wind and is securely fastened with a cable, Fig. 11.* The engine is put in motion and the propellers in the rear whir. You take your seat at the center of the machine beside the operator. He slips the cable and you shoot forward. An assistant,

*Now obsolete through adoption of wheeled chassis.—Ed.

who has been holding the machine in balance on the rail, starts forward with you but before you have gone 50 feet the speed is too great for him, and he lets go. Before reaching the end of the track, the operator moves the front rudder and the machine lifts from the rail like a kite supported by the pressure of the air underneath it. The ground under you at first is a perfect blur, but as you rise objects become clearer. At a height of 100 feet you feel hardly any motion at all, except for the wind which strikes your face. If you did not take the precaution to fasten your hat, you have probably lost it by this time. The operator moves a lever; the right wing rises, and the machine swings about to the left. You make a very short turn, yet do not feel the sensation of being thrown from your seat, so often experienced in automobile and railway travel. You find yourself facing toward the point from which you started. The objects on the ground now seem to be moving at a much higher speed, though you perceive no change in the pressure of the wind on your face. You know then that you are traveling with the wind. When you near the starting point, the operator stops the motor while still high in the air. The machine coasts down at an oblique angle to the ground, and, after sliding 50 to 100 feet, comes to rest. Although the machine often lands when traveling at a speed of a mile a minute you feel no shock whatever, and can not, in fact, tell the exact moment at which it first touched the ground. The motor beside you kept up an almost deafening roar during the whole flight, yet in your excitement you did not notice it until it stopped.

"Our experiments have been conducted entirely at our expense. In the beginning, we had no thought of recovering what we were expending, which was not great and was limited to what we could afford for recreation. Later when a successful flight had been made with a motor, we gave up the business in which we were engaged, to devote our entire time and capital to the development of a machine for practical uses. As soon as our condition is such that constant attention is not required, we expect to prepare for publication the results of our laboratory experiments, which alone made an early solution of the flying problem possible."

United States Government Requirements. The War Department had called for bids on heavier-than-air flying machines, and three aeroplanes were accepted for trial. The Wright machine was

one of these, and the others were submitted, one by A. M. Herring, and the other by James F. Scott. The official tests took place during the early part of September, 1908, at Fort Meyer, Virginia, across the Potomac from Washington. The Wright flyer was the only one of this type of flying machine to take part, although the Baldwin dirigible fulfilled the conditions required of it and was accepted, as has been mentioned before.

The conditions imposed by the War Department were generally believed by experts to be impossible of fulfillment. It was demanded that the machine should make an endurance flight of one hour; that it should have a speed of 40 miles an hour in still air; that it should be able to carry sufficient fuel for a flight of 125 miles; and that it should be capable of carrying two persons with a combined weight of 360 pounds. Three tests for speed and three for endurance were to be allowed.

It was required that during the endurance flight the aeroplane should remain continuously in the air for one hour, that it should be under perfect control, and that it should return to the starting point and alight without mishap. Further, it was demanded that the machine should be so designed as to be assembled and ready for operation within 60 minutes—the apparatus being of such construction as to be readily taken apart, transported in a couple of wagons, and put together again whenever wanted for service.

If these conditions were met, the government, it was understood, would pay $25,000 for the machine. They certainly seemed next to impossible, and nobody—least of all the army officers appointed to supervise the trial—imagined that they could be fulfilled. Only the Wrights themselves were confident. The machine offered for test was a new machine, never flown, and its construction embraced some novel features, the most important being a modification which enabled the aviator to sit erect.

Tests of 1908. On September 9, Oryille Wright made a continuous flight of 36 miles, staying in the air 57 minutes and 31 seconds. That evening, he made another flight of 38½ miles in 1 hour, 2 minutes, and 15 seconds. This not only broke all records but was a flight of over twice the duration of any previously made. He then took Lieutenant Lahm of the United States Army as a passenger for a short trip.

Three days later he stayed in the air 1 hour and 14 minutes, making a speed of nearly 29 miles per hour. No attempts at great altitudes were made, 250 feet being about the greatest height attained.

A deplorable accident occurred on September 17, which showed that the flyer was not yet proof against mechanical defects. On this trip, Orville Wright took Lieutenant Selfridge with him as passenger. When they were preparing to descend, after a very successful flight, one of the propellers caught in a stay wire and snapped. The machine fell to the ground, pinning the aviators under it. Lieutenant Selfridge was killed, and Wright received rather severe, but temporary, injuries. This accident prevented the completion of the government tests.

Wilbur Wright in Europe. *In France.* Meantime, Wilbur Wright, in France, was preparing to give demonstrations of his machine with a view to selling his French patents. At first he was not regarded very seriously in that country, and the French comic papers hailed him as "*le Bluffeur.*" They quickly acknowledged their mistake when, on September 21, he made a continuous flight of over an hour and a half at Le Mans.

World's Record Broken. On the last day of the year 1908, Wilbur Wright won the Michelin prize and $4,000 in cash, and made a new world's flying record of 2 hours, 18 minutes, and 33 seconds; official distance covered, 77 miles and 760 yards; actual distance, making allowance for the distance lost in turns, about 95 miles—the longest flight ever made by a heavier-than-air machine. Because of his success in France, Wilbur Wright sold his French patents to the Astra Company.

Flights in Italy. During March and April, 1909, Wright made some successful flights in Italy for the War Department. He taught some of the Italian officers the art, but his pupils still had something to learn, as one of them had an accident due to faulty steering. Wilbur Wright sold his Italian rights to a syndicate which is manufacturing his machines for military and other purposes.

United States Government Requirements Fulfilled. In the latter part of June, 1909, Orville Wright, assisted by his brother, again attempted to fulfill the conditions imposed by the United States War Department. The trials were made at Fort Meyer, Virginia,

as were those of the year before. A new motor was used and his early attempts were unsuccessful, because the engine had not been thoroughly tested.

In later attempts the machine failed to rise properly, and the inventors turned their attention to the starting power. They added about sixty pounds to the weight which gives the initial momentum, dug a deep pit to give the weight a longer fall, and lengthened the starting rail by about 12 feet. This seemed to remedy the trouble, for no further difficulty was encountered. On July 20, a new American record was established, Orville Wright remaining in the air over 1 hour and 20 minutes.

The first part of the government requirements were met a week later, when Orville Wright made a flight of nearly an hour and a quarter—carrying a passenger—at a speed averaging about 40 miles per hour. Incidentally, this broke his brother's best record for a flight with passenger made in France the year before.

On July 30, Orville Wright met the last test of his aeroplane at Fort Meyer, and for the first time in its history the government became possessor of a flying machine. On a straightaway course of 5 miles out and return, with a passenger, Lieut. Benjamin D. Foulois, Wright maintained a speed of something over 42 miles an hour, and won for himself and brother, in addition to the $25,000 contract price of the machine, a bonus of more than $5,000. The elapsed time of the flight, according to the official figures, was 14 minutes and 42 seconds.

The conditions of the speed test were as simple as they were severe. The aeroplane was required to fly 5 miles straightaway from the Fort Meyer parade grounds to and around an army balloon anchored at the end of the course and back to the starting point. For every mile of speed less than 40 miles an hour, a penalty of 10 per cent on the contract price of the aeroplane was to be deducted from that price, and for every mile in excess of 40 miles an hour attained during the flight, a bonus of 10 per cent was to be added. A speed of less than 36 miles an hour meant the rejection of the machine.

The course was over an exceedingly rough and dangerous country, so far as affording safe landing places for a flying machine was concerned, as it was made up of hills, valleys, and thick woods for almost

the entire distance. In addition to the landing difficulties the many air currents made this particularly treacherous territory.

The 5-mile limit was marked by a small army balloon anchored on Shuter's Hill, 2 miles back of Alexandria. Another balloon at Four Mile Run marked the middle of the course and served as a guide to the aeronauts. A field telephone was established between Shuter's Hill and the starting line.

Orville Wright established a new world record for aeroplanes in cross-country flying. No aeroplane had ever before flown across a country as rough and broken as lay under this course, and never

Fig. 12. Silver Dart, a Successful Model of the Aerial Experiment Association

before had a flight of equal distance been attempted by any aeroplane carrying two persons. Other cross-country flights had been made in France, but the conditions were more favorable.

Aerial Experiment Association. An organization which has accomplished a great deal that is of experimental value during its short life, was the Aerial Experiment Association at Hammondsport, New York. This was composed of such enthusiasts as Dr. Alexander Graham Bell, Glenn H. Curtiss, Lieutenant Selfridge (who met his death in the accident at Fort Meyer), and others. The association was organized in 1907 and lasted till 1909. Aside from the tests of Dr. Bell's tetrahedral kites, a most successful type of aeroplane was developed, the Silver Dart, illustrated in Fig. 12, being one of the several machines produced.

There are two distinctive features in the design. The first is the general principle and arrangement of the truss which supports the two surfaces, being a double bowstring truss, which was found to have structural advantages over the flat-bridge design commonly used. The other features which distinguish the machine from the usual type of double-deck machines lie in the shape of the supporting surfaces, which are very much like a bird's wing in plan, tapering toward the tips, and at the same time decreasing in curvature.

Red Wing. The Association's first aeroplane, the Red Wing, flew 318 feet above Lake Keuka on March 12, 1908. It has almost

Fig. 13. June Bug, an A. E. A. Machine

the same construction as the White Wing (which will be described in detail), except that it was mounted on runners. On its first flight the tail of the Red Wing buckled. This was a horizontal single-surface tail, and was then changed to a two-surface box shape much like that used on the Farman aeroplanes. In a flight a few days later, the aeroplane tipped and fell on the ice and was completely demolished.

White Wing. The next machine, the White Wing, was mounted on bicycle wheels. A wood propeller was used with an eight-cylinder, 40-horse-power, air-cooled Curtiss gasoline engine. The diameter of the propeller was a little over 6 feet. The aeroplane was 42 feet 6

inches long from tip to tip, and 4 feet deep at the outside panel. It had a total supporting area of 408 square feet, and weighed 430 pounds. A box-shaped tail like that used last on the Red Wing was mounted in the rear, and in the middle was a vertical rudder. A double-surface horizontal rudder was placed in front. The wing tips were pivoted at their forward edges and made to move up and down slightly by means of a cord attached to the aviator's body. It was thought that the instinctive leaning of the aviator to one side in making turns could be made to set the wings properly.

Fig. 14. View of Power Plant of Silver Dart, J. A. D. McCurdy at the Wheel

On one attempt, the White Wing covered over 1,000 feet. It was driven by G. H. Curtiss, and was his first flight. The machine touched earth once after covering about 600 feet, but at once rose and continued for another 400 feet.

June Bug. The next machine was the June Bug, shown in Fig. 13. In its construction, the June Bug had the two main superposed surfaces, with a spread of 42 feet 6 inches, including wing tips, and with a total supporting surface of 370 square feet. The motor was of 25 horse-power, with 8 cylinders, and a speed of 1,000 revolutions per minute. The total weight of the machine with motor was 650 pounds.

Silver Dart. The June Bug was superseded by the Silver Dart built under the direction of J. A. D. McCurdy, of the Aerial Experiment Association, who is seen at the wheel in Fig. 14. It made its first successful flight at the grounds of the Association at Stony Brook Farm on December 15, 1908. There were several trials, all of which proved satisfactory.

In the Silver Dart, the propeller was placed differently than in earlier machines. Not only was a forward motion for the whole machine obtained by the new arrangement, but a buoyant or lifting effect was also produced. The engine was of a similar design to the

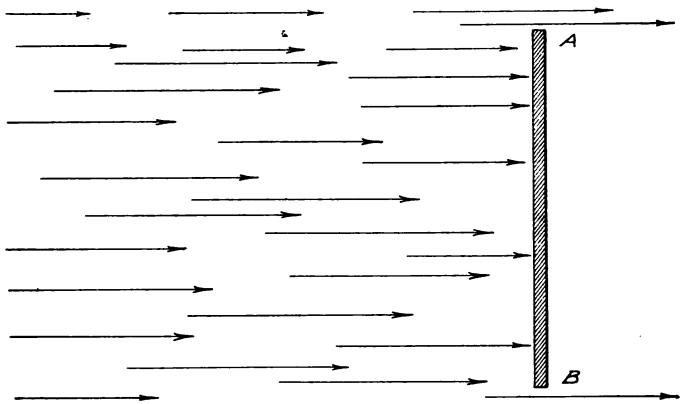

Fig. 15. Behavior of a Stationary Plane in a Current of Air According to Newton's Ideas

June Bug, but of twice the horse-power. An excellent view of the installation of the engine and propeller is given in Fig. 14. The total weight of the Silver Dart, including its burden, a man weighing, say 150 pounds, was 860 pounds.

Herring-Curtiss Company. The success attained by the machines of the Aerial Experiment Association, and especially the Silver Dart, was attracting wide-spread attention in Europe, and it was feared that, as in the case of the Wright Brothers, the benefits of these inventions would go to Europe. To prevent this, Courtland Field Bishop, president of the Aero Club of America, formed a company, in which the interests of Glenn H. Curtiss and A. M. Herring were combined. Curtiss' motorcycle and aeronautic motor factory was taken over by this company, and afforded an excellent base for beginning operations. Herring claims to own basic patents on the

only solution of anything approaching automatic control of aeroplanes so far proven practicable. With the organization of the Herring-Curtiss Company came the dissolution of the Aerial Experiment Association.

ELEMENTARY AERODYNAMICS

Air Resistance. While an extended study of the theoretical side of flight would involve going deeply into mathematics and would in itself require a volume for its exposition, it is essential for the student to know at least the principles upon which flight is based; especially as applied to the design of the successful aeroplanes. The most important single factor is the resistance of the air, and a knowledge of its bearing upon aviation, particularly in the consideration of the pressure on the surface of an aeroplane, is fundamental. Although it has been the subject of study for centuries, it has been only within comparatively recent times that either the true nature of the atmosphere, or reliable data concerning its action, has been formulated. For instance, Sir Isaac Newton, in his "Principia," defines air as an "elastic, non-continued, rare medium consisting of equal particles freely disposed at equal distances from each other." In accordance with this, if *AB*, Fig. 15, is a section of a surface against which a stream of air is blowing, all the particles of air strike directly against the surface, as indicated by the arrows. In contrast with this, Newton defined water, oil, etc., as "continued mediums," in which all the particles generating the resistance do not come in immediate contact with the surface. The latter is pressed upon only by the particles that lie next to it; these in turn being pressed by those beyond, and so on. The character of this fluid pressure is shown by Fig. 16, and subsequent investigators in demonstrating the fallacy of Newton's theory, show that air, as a medium, is similar in character to water, so that Fig. 16

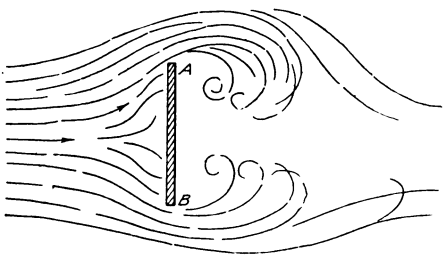

Fig. 16. Correct Idea of Air Currents Set Up by a Plane

also illustrates the action of a stream of air in striking a flat surface held at right angles to its course.

Newton calculated that the resistance of a "continued medium" varies in the "duplicate ratio of the velocity," and directly as the density of the medium itself. Robins, in 1746, with a view to determining the resistance of the air to cannon balls, whirled planes and spheres about a circular orbit, and found that the resistance varied directly as the square of the velocity. This was also determined to be true in various ways by later experimenters, Rennie having so abundantly verified this relation for low velocities in 1830, that it has since been accepted without question.

Constant K of Air Resistance. But to accurately calculate the pressure on a given surface, we must have another factor and that is the density of the medium pressing against the surface. There is a great deal of variance between different investigators regarding the value of this factor, but once it is known, the resistance of the air may be expressed in terms of pounds pressure by the following formula:

Pressure equals constant $\times$ *area* $\times$ *velocity squared*

or

$$P = KAV^2$$

where K is the "constant of air resistance," the value of which depends upon the density (barometric pressure) and temperature of the air and the character of the surface of the plane. This equation may be derived from the laws of mechanics as follows:

Let W equal the weight of the air directed against any normal surface in a given time; w equal weight in pounds of one cubic foot of air; V equal velocity of the air stream in feet per second; A equal area of surface on which pressure acts; M equal mass of air of weight W; g equal acceleration due to gravity, or 32.2 feet per second; and P equal pressure on the area A. Then the total weight W will equal the product of the weight of the total number of cubic feet w, times the area, times the velocity, or

$$W = wAV$$

But the momentum of the force on the area is equivalent to the mass times its velocity; and if A be assumed to equal one square foot, w equals 0.0807 pounds, or the weight of air per cubic foot at

32°F. and 30 inches barometric pressure, and V may be expressed in miles per hour. Then, since $VP = MV$,

$$P = .0054\ V^2$$

K thus taking the theoretical value .0054 where V is expressed in miles per hour and P in pounds per square foot.

In 1759, Smeaton deduced the formula $P = .005\ V^2$, and considering A as unity, he published a table of velocity and pressure of the wind. His actual value for K was .00492, but it early became customary in engineering practice to take it as .005. This table was regarded as a standard in engineering textbooks for years, but as long since it has been shown to be erroneous, it is not given here.

Numerous other investigators have deduced the value of K as ranging all the way from .0025 to .0055. In 1842 Colonel Duchemin derived it as .00492 and published the results of a thorough series of experiments which have proved very valuable. Early investigators erred, however, in the method of making their experiments which were conducted with the aid of a revolving member or "whirling table," and overlooked the disturbing effects of the cyclonic action thus set up. The values deduced by more recent experimenters employing surfaces either held rigid against the stream of air, or moved directly into it, are as follows:

Col. Renard	1887 $K = .00348$
Langley	1888 $K = .00389$ to $.00320$
Lilienthal	1889 $K = .005$
Voisin	1900 $K = .0025$
Wright Brothers	1901 $K = .0033$
Eiffel	1903 $K = .0031$

Eiffel was among the first to recognize two sources of inaccuracy —the neglect of the consideration of separate air filaments which vary at different points on the surface, and the cyclonic action of the air due to a revolving source. His experiments were carried out on the Eiffel Tower. The surface was attached to a carriage by springs, the pressure being recorded on a blackened cylinder. The carriage was allowed to fall vertically about 312 feet and was constrained in its motion by a vertical cable.

The coefficient K varied remarkably little and was practically determined as .0031. He also found, that between 700 and 1,300 feet per second the pressure was proportional to the square of the

velocity, but that at about 1,300 feet per second, it began to increase and vary as the cube. As it is unlikely that aeroplanes will ever reach such velocities, this is a factor that need not be considered.

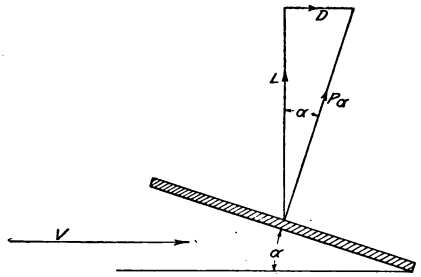

Fig. 17. Diagram Showing Lift and Drift of a Plane

Out of the great number of experiments of this kind, conducted in various ways, those carried out on the Berlin-Zossen electric line in 1903 are undoubtedly the most accurate as well as the best applicable to the actual conditions of a large body moving through the air at high speed. Velocities as high as 120 miles an hour were attained and the air resistance carefully measured by an elaborate set of pressure gauges. The mean value of the results as plotted on a chart gave $P = .0027\ V^2$.

Comparing the result of grouping the values as determined in three different ways and taking their average, we have

(1) $K = .0054$ (by theory)
(2) $K = .0042$ (by rotating apparatus)
(3) $K = .0029$ (by movement in a straight line)

For the purpose of calculations of pressures on an aeroplane, the third is naturally the most accurate, so that for figuring air pressures as applied to aeroplanes, the most practical expression of such pressure is $P = .003\ AV^2$, where $K = .003$.

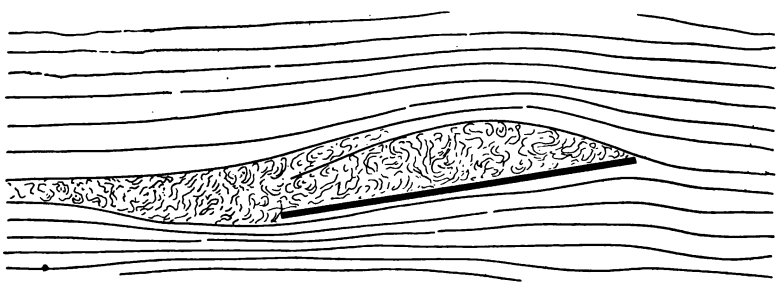

Fig. 18. Disturbances Caused in Air by a Plane at a Small Angle of Incidence

Air Pressure on Moving Surfaces. *Plane Surfaces.* This is the starting point in all aeroplane calculations. Next comes the

action of different forms of surfaces when moved forward through the air. Investigations of this phase of the subject also date back to Newton, but a great deal of the work of early experimenters was shown to be wrong by Langley, who verified Duchemin's neglected formula of 1842.

Assuming P_a to represent the pressure acting perpendicularly to the surface of a plane inclined at an angle in a wind current of velocity V, we may resolve it into two components at right angles; one acting perpendicularly and equal to L, and another acting hori-

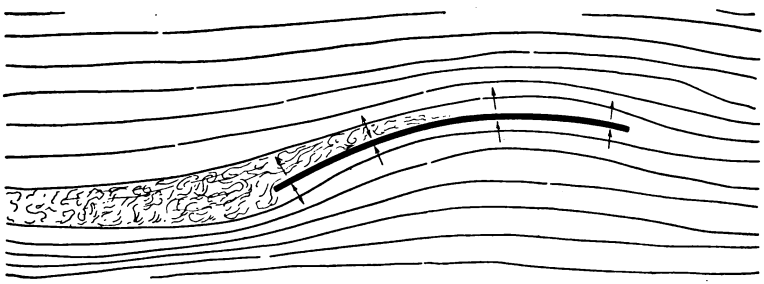

Fig. 19. Disturbances Caused in Air by a Curved Plane at a Small Angle of Incidence

zontally and equal to D, Fig. 17. In the present terminology of aerodynamics, L is termed the *lift* and D the *drift* of a plane. Then

$$D = P_a \sin \alpha$$

and

$$L = P_a \cos \alpha$$

This was resolved as early as 1809 by Sir George Cayley and has since been verified by Langley and by actual practice. The ratio of these two quantities LD, termed the *ratio of lift to drift*, is the means of expressing the aerodynamic efficiency of the supporting surface of an aeroplane.

Curved Surfaces. Up to Lilienthal's time all experiments had been made with flat surfaces and as the result of his study of birds' wings, he was the first to recognize that even very slight curvatures of the plane profile (section) considerably increased the lifting power. The reactions and disturbances of flat and curved planes traveling through the air are graphically illustrated by Figs. 18 and 19. In a flat plane, the pressure is always perpendicular

to the surface and, as already pointed out, the ratio of lift to drift is, therefore, as the cosine to the sine of the angle of incidence. The angle of incidence is the angle at which the plane is inclined to the air current. But in curved surfaces, Fig. 20, as first shown by Lilienthal, the pressure is not uniformly normal to the chord of the arc, but is

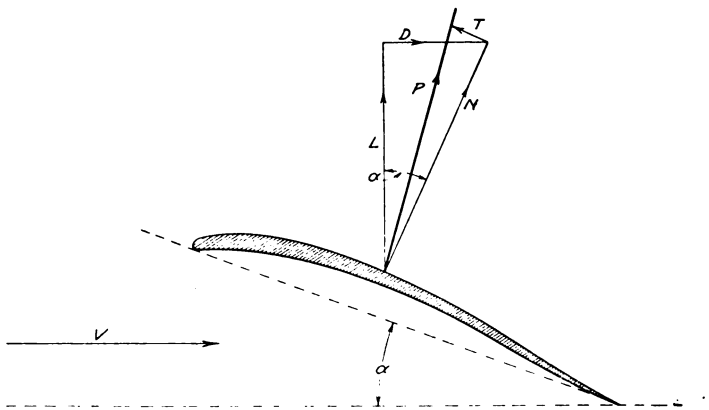

Fig. 20. Resolution of Force Diagram for a Curved Plane

considerably inclined forward of the perpendicular, with the result that the lift is increased and the drift decreased. He stated it as follows:

When a wing with an arched surface is struck by the wind at an angle a with a velocity V, there will be generated a pressure P, which is not normal, but is the resultant of a force N, normal to the chord, and of another force T, tangential to the chord.

Taking A as the area of the wing, and .005 as the coefficient of air resistance, it is apparent that—

$$N = n \times .005 \times A \times V^2$$
$$T = t \times .005 \times A \times V^2$$

Values of n and t, which represent constants used by Lilienthal, show the arched surfaces still possess supporting powers when the angle of incidence becomes negative, *i.e.*, below the horizontal. The air pressure P becomes a propelling force at angles exceeding 3 degrees up to 30 degrees.

As Chanute pointed out, this does not mean that there is no horizontal component, or drift, of the normal pressure N under these conditions, but that, at certain angles, the tangential pressure T, which would be parallel to the surface and only produce friction in the case of a flat plane, acts on a curved surface as a propelling force. The experiments of the Wright Brothers at Kitty Hawk,

North Carolina, verified the existence of Lilienthal's tangential, and experiments conducted by them later in their laboratory further supported this fact, though their results differed from Lilienthal's at angles below 10 degrees. Fig. 20 illustrates the resolution of forces on a curved plane, L and D being the lift and drift as obtained from the effective pressure N.

Lilienthal prepared a table giving the values of n and t on an inclined surface, on a basis of $1\frac{1}{2}$ curve from zero to 90 degrees, and a comparison of this with the experiments of Langley on flat surfaces exhibits at once the greater lifting effect of curved surfaces, though Wilbur Wright is of the opinion that Lilienthal's values are somewhat too large at angles below 9 degrees. Although many excellent treatises have been written on the subject, it is hardly possible with the present knowledge of aerodynamics to explain exactly what the significance of these values n and t are, or to bring them under any well-known set of physical laws.

An examination of the photographs of stream lines of air obtained by such experimenters as Marey, Hele-Shaw, and Mach and Akborn, suggests that a surface with a pronounced curve at the front would tend to produce a vortex action under the front edge, when the current of air is swift enough, and recent investigations indicate that such action increases the dynamic resistance enormously as the speed increases. In racing machines, therefore, the curved surface so widely used in slower machines is being gradually departed from and in its stead, a surface with a flat under side and a curved upper side, having considerable thickness at the center, is being substituted. The air stream is thus guided smoothly over the upper curved surface, while the lower flat face permits of a much easier flow, and consequently of a decrease of dynamic resistance, or drift. The decrease in the lift thus occasioned is compensated for by higher velocities due to increased motor power. Just how much the lift is decreased can be shown only by actual practice. This flattening of the under side of the supporting surface has a great disadvantage in that it tends greatly to lessen the stability of the machine.

Ratio of Lift to Drift. The ratio of lift to drift is of great importance in the design of aeroplanes, and the surface having the greatest ratio under working conditions is the most efficient from an aerodynamic standpoint, *i.e.*, it carries the greatest weight with the

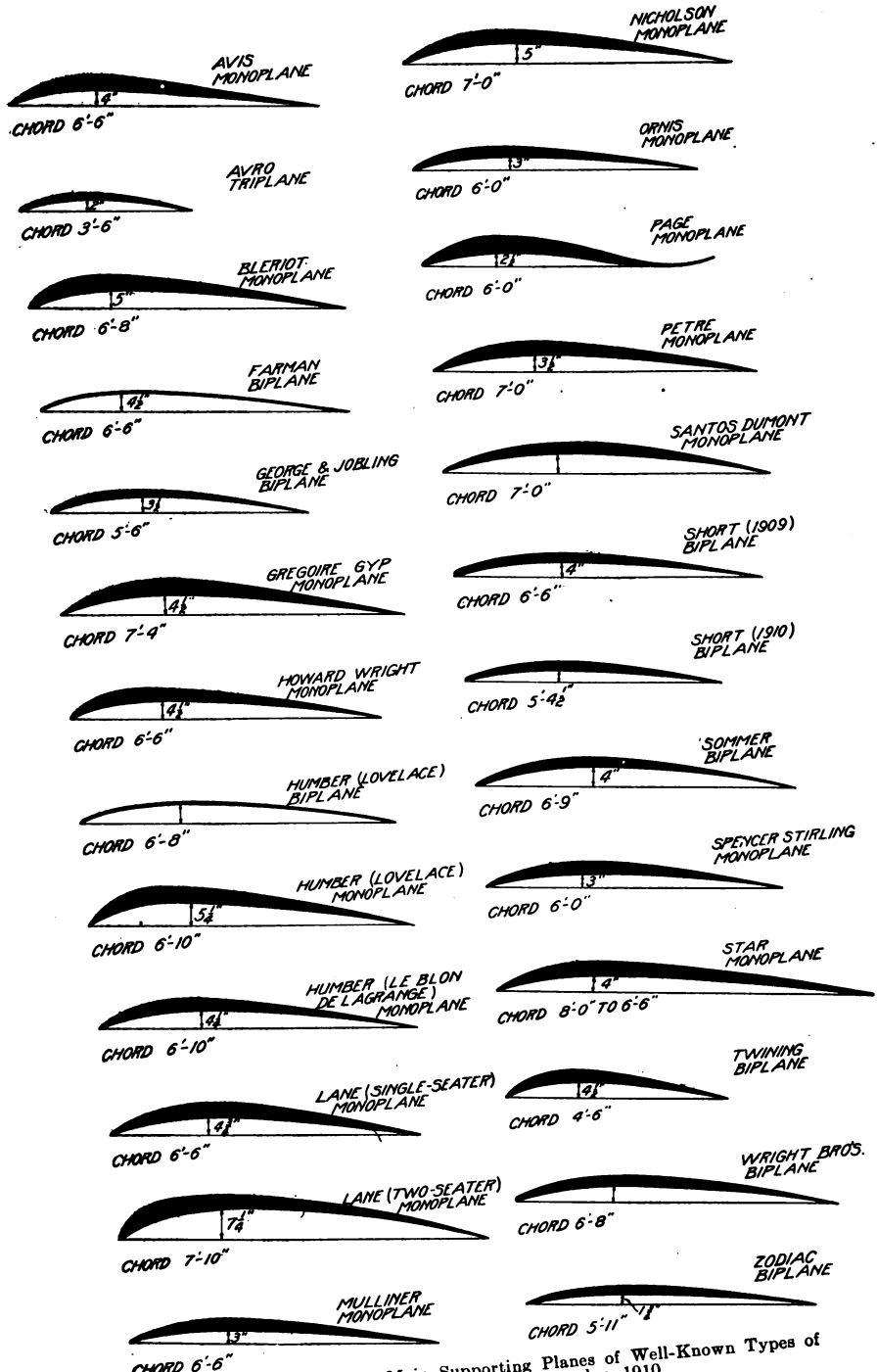

Fig. 21. Sections of Main Supporting Planes of Well-Known Types of Aeroplanes Shown in London, 1910

least power. The large value of the ratio for small angles shows arched surfaces to be the most economical in flight. The manner in which various prominent designers have worked out the problem in actual practice is illustrated by the comparison of the different sections of the supporting surfaces, or planes, of the machines exhibited at Olympia, London, 1910, Fig. 21. The experiments on the relation of sustaining power to head resistance, on various planes, show that a thick, curved plane is very efficient, as well as by far the most stable. The Antoinette monoplane is equipped with surfaces of this form. (See upper diagram, Fig. 28, in "Types of Aeroplanes.")

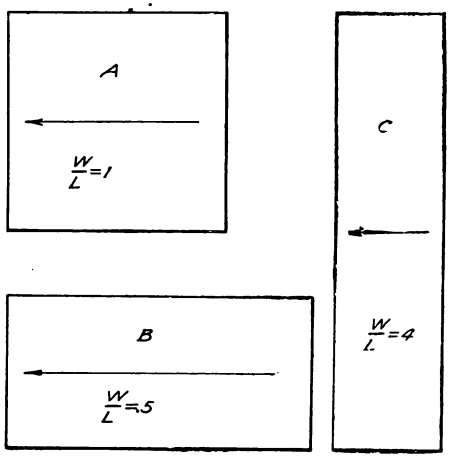

Fig. 22. Aspect Ratio of Planes

Aspect Ratio. "Aspect ratio" is the term commonly employed to indicate the ratio of spread, *i. e.*, width of the supporting surfaces, to their depth. It is a feature of greater importance than the curvature of the plane itself, in that it determines to a considerable extent the lifting power of the latter. At first glance, it would seem that a given area of surface at a certain angle of incidence and moving at a stated speed would produce a definite lifting reaction, regardless of the plan form of the surface. This is not the case, however, as can be simply demonstrated. The plan form and its aspect or direction of presentation are items of the greatest importance in determining the lifting power per unit of area. Obviously, the lifting or supporting reaction of the air upon a surface depends upon the amount of air displaced or acted upon by it in a unit of time. Fig. 22 shows three equal surfaces of rectangular plan form, varying in their respective ratios of width to length, the length being in each case measured parallel to the line or axis of flight.

If each of the three surfaces shown, *A*, *B*, and *C*, is given the same angle of incidence and is moved along its line of flight at the same speed, the amount of air acted upon in unit time (the measure

of the relative supporting powers) will naturally vary among the three surfaces as the width of the presented edge. That is, for equal rectangular areas of supporting surface, at the same speed and angle of incidence, the supporting powers vary as the ratios of the widths to lengths along the axes of flight. In Fig. 22, then, if the surface *A* will support 1 pound, *B* will support .5 pound and *C* will support 4 pounds, all other conditions being identical. Of course, these figures are modified considerably by the heights and depths to which the air is acted upon by the passage of the surfaces, and, since these values vary directly but in reduced ratios, as the axial lengths of the compared surfaces, it will be apparent that *C* will not actually lift eight times as much weight as *B*. However, the rate of gain is very much higher than the rate of loss, as the width or spread is extended and the depth correspondingly decreased, as strikingly shown by the simple comparison just given. In the case of plane *A*, the aspect ratio is 1 to 1; in *B* it is .5 to 1, or what might be termed a negative aspect ratio; in *C* it is 4 to 1. By referring to "Types of Aeroplanes," it will be noted that the usual aspect ratio employed in actual practice varies between 5 and 7 to 1.

As a matter of fact, the efficiency of the supporting reaction increases almost indefinitely with an extension of the width to length ratio and in practice is limited only by constructional considerations. This is shown in nature by the extremely great spread of wing of the soaring birds as compared with their depth. For instance, the man-of-war hawk, a tropical marine bird, has a spread of wing of several feet while its depth is but a few inches (plane *C*). It is very rarely seen to move its wings in flight, but soars practically motionless at altitudes of several hundred to a thousand feet. The common black crow of northern latitudes, on the other hand, has a wing more closely approximating plane *B*, considering the upper edge of this to be the one presented to the air, instead of the left-hand edge as in the illustration. Birds of this class are slow and heavy fliers and have to flap their wings constantly.

Weight for weight, the structure of surface *B* can be made stronger than *A*, even as *A* is inherently stronger than *C*, and the limit of extension of the aspect ratio is determined only by strength considerations in the completed surface. Average practice in this respect places the ratio at about 6 to 1.

Skin Friction. By analogy with the great frictional resistance of a body in water, it would seem as if the friction of the air would also be considerable. This is termed *skin friction* and, in their experiments, many early investigators put it down as practically a negligible factor. Professor Zahn went into this thoroughly in 1903 and determined that the friction of the air on surfaces is an important factor. He expressed its general value in the formula $F = .0000158\, L^{.93} v^{1.05}$, where F is the frictional drag in pounds per square foot, L is the length of the surface in the direction of motion in feet, and v is the velocity of the air past the surface in miles per hour. The friction was found to be approximately the same for all smooth surfaces, but 10 to 15 per cent greater on extremely rough surfaces, which accounts for the care with which the supporting surfaces of an aeroplane are made smooth. It is now generally accepted that skin friction is an appreciable factor in the resistance of an aeroplane, amounting to, in an average-sized machine, from 10 to 15 pounds.

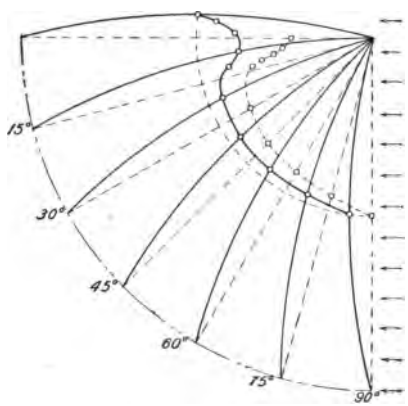

Fig. 23. Locus of Center of Pressure for Various Angles of Incidence for Curved Plane

In his experiments to determine head resistance and skin friction, Langley employed a rotating table with a collapsible arm holding a straight plane cutting edge of a given area, which could be moved at different speeds. He found that 256 square feet of skin-frictional surface developed approximately 1 pound resistance at a speed of 30 miles an hour. It was also found that cutting edges with straight surfaces and sharp angles developed almost double the resistance of a cutting edge with a spherical surface, while an elliptical surface had but half the resistance of a sphere.

Center of Pressure. Newton assumed that when a rectangular plane was moved through the air at an angle inclined to the line of motion, the center of pressure and the center of surface were always coincident. This is not the case, however, the center of pressure varying as the angle of incidence. Numerous experimenters inves-

tigated this with practically similar results, Langley's experiments with his "counterpoised eccentric plane" having been of this nature. But all these experiments were on flat surfaces and the movement of the center of pressure on curved surfaces is totally different. In deeply-arched surfaces, it moves steadily forward from the center of surface as the inclination is turned down from 90 degrees, until a certain point is reached, varying with the depth of curvature, Fig. 23. After this point is passed, a curious phenomenon takes place. Instead of continuing to move forward with a decrease of

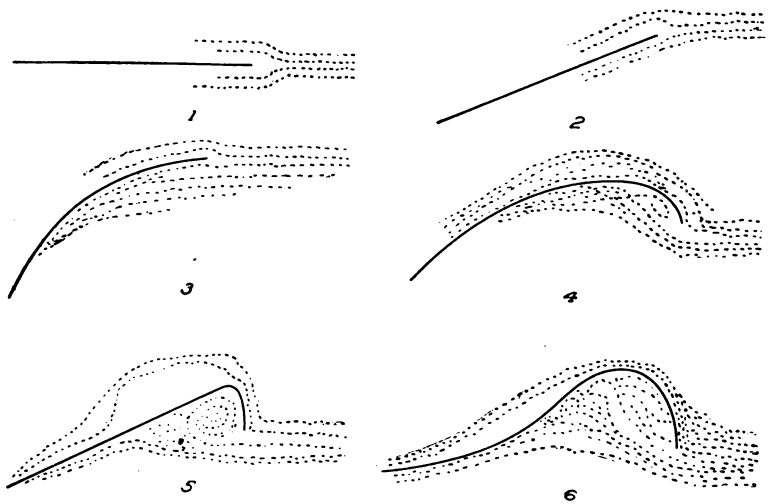

Fig. 24. Six Stages of Development of the Aeroplane Supporting Surface

angle, the center of pressure turns abruptly and moves rapidly to the rear. According to Wilbur Wright, this action is due largely to the pressure of the wind acting also on the upper side of the arched surface at low angles. The action is unmistakable and has often been observed in practice; the reversal, which, according to Rateau, occurs as the angle of 15 degrees is approached, strikingly illustrates the difference in the conditions of pressure on a curved surface at low angles as compared with those of flat surfaces. A region of instability at 30 degrees also appears to be present in a curved surface.

Evolution of Curved Supporting Surface. The foregoing emphasizes the great importance of the proper curvature of the supporting surfaces of an aeroplane, and the evolution of this curve has

been so minute and apparently so insignificant that its actual importance is not appreciated except by the experienced designers of machines. Going back to before Lilienthal's time, it may be said to progress in six stages, Fig. 24: *First*, the flat plane, held horizontally. *Second*, at an angle of incidence. (With neither of these was there any hold on the air.) *Third*, the true arc of a sphere was employed and with this curve the feat of lifting a man in gliding flight was first accomplished, due primarily to the fact that the air was not thrown off at such a sharp angle as in the straight plane. It caused the air to compress more and more to the rear of the curve, or moved the center of pressure backward. *Fourth*, the next step was to bend the forward edge of the arc downward sharply, forming a parabolic curve and causing the air to shoot upward at the point of contact, giving a powerful lift. *Fifth*, then followed the remarkable discovery that with a certain form, the upper surface of the plane exerts as much lift as the under side. This was obtained by taking a flat plane, held at an angle of incidence, and abruptly bending its forward edge downward, practically at right angles. By this construction, the air was thrust upward on the outer surface, while the air, rushing in underneath to fill the partial vacuum thus formed, exerted a powerful lift and, at the same time, was pushed forward, thus tending to diminish the head resistance. Still more important was the fact that the air, which was shot vertically upward by the butt edge of the curve, tended to raise the plane with it, giving an upward thrust or lift almost as great as that beneath the surface. In the final stage, the plane itself is no longer flat but curved upward as shown in the figure. In Fig. 24, these curves have been greatly exaggerated, but their influence will be apparent upon studying sections of the supporting planes of well-known types of machines.

The reason for not employing such exaggerated curves is because of the excessive head resistance that would be created. By far the greatest factor to be dealt with in the design of an aeroplane is the resistance to motion. On its elimination as far as possible depend the ability to fly, the speed, and the power efficiency. The total resistance may be divided into three parts: *First*, the head resistance of the framing and body; *second*, the drift of the plane or planes; and *third*, the frictional or skin resistance of the whole. To fly, this combined resistance must be overcome by the thrust of the propeller.

INTERNAL WORK OF THE WIND

Character of Air Currents. Before the researches of Langley showed its true nature, the wind was commonly assumed to be a homogeneously moving body. In other words, where not influenced by terrestrial obstructions, a wind blowing at a certain speed represented a uniformly-moving current of air, at any point in the body of which the moving air would be found to have the same speed and the same direction of travel. The subject is one of great importance to the aviator, and a knowledge of it, in outline at least, is essential to an understanding of many things that otherwise are inexplicable.

Instead of being a homogeneously moving body, Langley found that a current of air, even where movements only in one horizontal plane are considered, is always filled with amazingly complex motions. Some of these, if not in opposition to the main movement, are relatively so—that is, are slower, while others are faster than this main movement, so that there is always a portion opposed to it. These irregular movements of the wind, which take place up, down, and on every side, are accompanied by equally complex condensations and expansions, but it will be apparent that only a small portion, those occurring in a narrow current whose direction is horizontal and sensibly linear, could be recorded by the anemometer. However complex the movement may appear as shown by the records of the instrument, it is then far less so than the reality.

Movements of a Plane in Wind. *With Vertical Guides.* We will presently examine the means of utilizing this potentiality of internal work in order to cause an inert body wholly unrestricted in its motion and wholly immersed in the current, *to rise;* but first let us consider such a body (a plane) whose movement is restricted to a horizontal direction, but which is free to move between frictionless, vertical guides. Let it be inclined upward at a small angle (angle of incidence) to a horizontal wind, so that only the vertical component of pressure of the wind on the plane will affect its motion. If the velocity be sufficient, the vertical component of the pressure will equal or exceed the weight of the plane, and in the latter case, the plane will rise indefinitely.

For example, if the plane be a rectangle whose length is six times its width with an area of 2.3 square feet to the pound and an

inclination at an angle of 7 degrees, and if the wind have a velocity of 36 feet per second, experiment shows that the upward pressure will exceed the weight of the plane, and the latter will rise (if between vertical, nearly frictionless guides) at an increasing rate until it has a velocity of 2.52 feet per second, at which speed the weight and upward pressure are in equilibrium. (Langley, "Experiments in Aerodynamics.") Hence, there are no unbalanced forces acting and the plane will have attained a state of uniform motion.

For a wind that blows during 10 seconds, the plane will, therefore, rise about 25 feet. At the beginning of the movement, the inertia of the plane makes the rate of rise less than the uniform rate, but at the end of 10 seconds, the inertia will cause the plane to ascend a short distance after the wind has ceased, so that the deficit at the beginning will be counterbalanced by the excess at the end of the assigned interval.

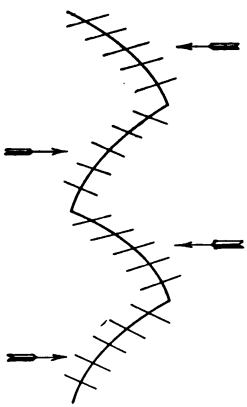

Fig. 25. Movements of a Free Plane in Air

Without Vertical Guides. Such a plane will be lifted and sustained *momentarily*, even if there be no vertical guides, or, in the case of a kite, if there be no cord to sustain it, the inertia of the body supplying for a brief period, the office of the guides or cord. If suitably disposed, it will commence to move under the resistance imposed only by its inertia to a horizontal wind, not in the direction of the wind, but nearly vertically. As the plane takes up more and more the motion of the wind, this inertia is overcome and the lifting effect decreases, that is, if the wind be the approximately homogeneous current it is commonly treated as being, and finally the plane falls. If, however, a counter-current be supposed to meet this inclined plane before its inertia is exhausted and consequently before it ceases to rise, it is only necessary to assume its revolution through 180 degrees about a vertical axis, to see that it will be lifted still higher without any other call for expenditure of energy, as its inertia now reappears as an active factor. Fig. 25 shows what might be assumed to happen to a model inclined plane freely suspended in the air, and endowed with the power of rotating about a vertical axis so as to change the aspect of its constant inclination, which

need involve no theoretical expenditure of energy, even though the plane possess inertia. It is evident that the plane would rise indefinitely by the action of the wind in alternate directions. The disposition of the wind, which is here supposed to cause the plane to rise, appears at first an impossible one, but it becomes virtually possible by a method which we will now point out and which leads to a practicable one which *we may actually employ*. (It must be borne in mind that these experiments were carried out in 1893—ten years before the first flight of the Wright Brothers.)

Behavior in Pulsating Wind. Fig. 26 shows the wind blowing in one constant direction, but alternately at two widely-varying velocities, or rather, in the extreme case supposed in the illustration, where one of the velocities is negligibly small, and whose successive pulsations in the same direction are separated by intervals of calm. A frequent alternation of velocities, united with constancy of absolute direction, has been shown to be the ordinary condition of the wind's motion; but attention now is called particularly to the fact that while these unequal velocities may be in the same direction as regards the surface of the earth, yet as regards the *mean* motion of the wind they are in opposite directions, and will produce on a plane, whose inertia enables it to sustain a sensibly uniform motion with the mean velocity of this variable wind, the same lifting effect as if these same alternating winds were in absolutely opposed directions, provided that the constant inclination of the plane alternates in its aspect to correspond with the changes in the wind.

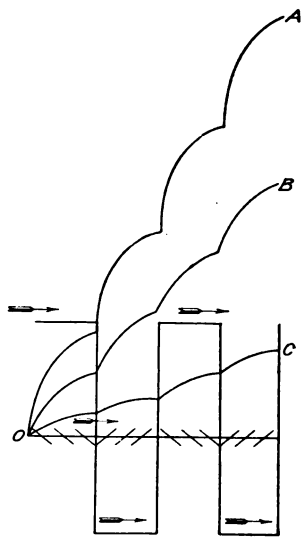

Fig. 26. Movements of a Free Surface in a Pulsating Wind

It may aid in clearness of conception, if we assume a set of fixed co-ordinates, X, Y, Z, passing through O, and a set of movable co-ordinates, x, y, z, moving with the velocity and direction of the mean wind. If the moving body is referred to the first only, it is evidently subject to pulsations which take place in the same directions

on the axis of X, but it must also be evident that if referred to the second, or movable co-ordinates, these same pulsations are in opposite directions. This, then, is the case we have just considered, and if we suppose the plane to change the aspect of its inclination as the direction of the pulsations changes, it is evident that there must be a gain in altitude with every pulsation, while the plane advances horizontally with the velocity of the mean wind.

During the period of maximum wind velocity, when the wind is moving faster than the plane, the rear edge of the latter must be elevated. During the period of minimum velocity, when the plane, owing to its inertia, is moving faster than the wind, the front edge of the plane must be elevated. Thus the vertical component of the wind pressure as it strikes the oblique plane tends in both cases to give it a vertical upward thrust. So long as this thrust is in excess of the weight to be lifted, the plane will rise. The rate of rise will be greatest at the beginning of each period, when the relative velocity is greatest and will diminish as the resistance produces "drift," *i.e.*, diminishes relative velocity. The curved line *OB*, Fig. 26, represents a typical path of the plane under these conditions.

It follows from the diagram, Fig. 25, that, other things being equal, the more frequent the wind's pulsations, the greater will be the rise of the plane; for since during each period of steady wind the rate of rise diminishes, the more rapid the pulsations, the nearer the mean rate of rise will be to the initial rate. The requisite frequency of pulsations is also related to the inertia of the plane, for the less the inertia, the more frequent must be the pulsations, in order that the plane shall not lose its relative velocity.

Soaring. It is obvious that there is a limit of weight which can not be exceeded if the body is to be sustained by any such fluctuations of velocity as can be actually experienced. Above this limit of weight the body will sink. Below this limit, the lighter the body is, the higher it will be carried, but with increasing variability of speed. That body, then, which has the greatest weight per unit of surface will soar with the greatest steadiness, if it soar at all, not on account of its weight, *per se*, but because the weight is an index of its inertia.

The student who will compare the results of experiments made with any artificial flying model, like those of Penaud, with the weights

of the soaring birds, as given in the tables by Mouillard, or other authentic sources, can not fail to be struck with the great weight in proportion to wing surface which Nature has given to the soaring birds, compared with any which man has been able to imitate in his models.

This great weight of the soaring bird in proportion to its wing area has been again and again noted, and that without weight the bird could not soar has been frequently remarked by writers who felt that they could very safely make such a paradoxical statement in view of the evidence nature everywhere gave that this weight was in some way necessary to rising. But these writers have not shown, so far as I remember, how this necessity arises, and this is what I now endeavor to point out.

The evidence that there is *some* weight which the action of the wind is sufficient to sustain permanently under these conditions in a free body, has a demonstrative character. It is obvious that, if this weight is sustainable at any height, gravity may be utilized to cause the body to descend on an inclined course to some distance. This is now a matter of such common experience that French aviators term it *volplane*, the action itself already having been anglicized as "volplaning." Seventeen years after Langley wrote it, Drexel gave a striking example of its truth by volplaning from a height of more than 9,000 feet, reaching the earth at a point 15 miles distant.

We have already seen how pulsations of sufficient amplitude and frequency, of the kind which present themselves in nature, may, in theory, furnish energy sufficient not only to sustain but actually to elevate a heavy body moving in and with the wind at its mean rate. It is easy now to pass to the practical case, exemplified by the bird, which, soaring on rigid wings, but having power to change its inclination, uses the elevation thus gained to move against the wind without expending any sensible amount of its own energy. Here the upward motion is designedly arrested at any convenient stage, *i.e.*, at each alternate pulsation of the wind, and the height attained is utilized so that the action of gravity may carry the body by its descent in a curvilinear path, if necessary, against the wind.

As the remainder of this particular study of Langley's is devoted to demonstrating the practicability of the theories here propounded, it would not be profitable to follow them any further. They are

now a matter of more or less common knowledge, having long since been raised from the realm of theory. But the influence of the "internal work of the wind," or rather its "internal character" if it may be so termed for purposes of illustration, upon the actual operation of the aeroplane, is of the greatest importance, and moreover it is something about which there is yet a great deal to be learned.

Air Holes. The deaths of Moissant at New Orleans, and Hoxsey at Los Angeles, on December 31, 1910, gave rise to a great deal of discussion regarding the uncertain character of the atmosphere as affected by the wind, and emphasized the fact that very little is actually known concerning it. Both being experienced aviators of a conservative type, it was difficult to account for the accidents (nothing apparently having gone wrong with either machine) except on the ground that the machine had suddenly dropped into a depression in the atmosphere, causing it "to stand on its head" and fall. The latter theory is supported in Hoxsey's case by an instantaneous photograph of his machine taken at the moment it started to fall, and showing it in apparently perfect condition, coming down in a perfectly vertical line. A more plausible explanation, however, is that Hoxsey, having just descended from a great altitude to within 500 feet of the earth, was overcome by the sudden change in pressure (see article on "Altitude"), and lost consciousness. In so doing, his body may have pitched forward against the lever of the elevating rudder, and so operated the latter as to head the machine vertically downward. This could not have been so in Moissant's case as he had not been up more than a hundred feet, the accident being ascribed by some of his fellow aviators to the fact that he attempted to land with the wind, contrary to the usual custom.

Whether or not either of these fatalities was due to these "pockets" or "holes" in the air, as they have come to be popularly termed, will never be known, but the fact that the atmosphere (wind) instead of being a homogeneous current of air, the character of which may be depended upon, is a complex mass of points of high and low velocity, or none at all, is an element that must be contended with by every aviator. Unlike the sailor, he can not see an unusual wave coming, nor can he determine deeps and shallows by the appearance of the surface. It is only when the wave or gust has struck the machine, or the machine itself has passed into one of the pockets

in the air, that the aviator knows how big or strong it is going to be, or how far the sudden fall in pressure due to passing over a calm spot will drop the machine. One of the troubles of aviators at exhibition meets is that the spectators do not appreciate the danger of these wind waves and holes and so expect them to fly in weath r that is really dangerous, although it may appear fine.

Effect of Eddies and Waves. On an open plain of considerable extent, such as that at which the aviation meets at Rheims are held, there is nothing to interfere with the wind and it blows more steadily, though as Langley has pointed out, the existence of swirls and eddies in the wind is independent of the influence of obstructions. It is well known, however, that the presence of obstructions gives it a totally different and far more dangerous character. Where there are hills, banks, and trees all around, the wind, even when blowing comparatively gently, comes in dangerous waves, swirls, and eddies, just like the eddies and whirlpools in a stream that has rocks or other obstructions to impede the flow of the water.

To properly understand the effect of these waves and eddies on an aeroplane, the theory of the flight of the latter must be borne in mind. The machine is sustained in the air, because the speed at which it is driven produces a pressure under its supporting surfaces exceeding its total weight; hence, the pressure lifts it. If driven faster, the pressure is increased and its sustaining power is greater; if driven slower, this is decreased and the machine tends to fall. In fact, we have the anomaly of prizes being offered for machines that are able to fly slowly. For example, if a machine be capable of a speed of 40 miles an hour, this represents a close approximation of its critical speed—in other words, it must fly that fast or not at all. By speeding up the motor, it may be able to fly a few miles an hour faster, but it can not fly much slower and still sustain itself in the air —in the case of the 40-mile-an-hour machine, probably not much less than 34 miles an hour.

Owing to its weight, ranging from 500 pounds in the case of a small monoplane, up to almost a ton for some of the largest biplanes, the inertia due to the high speed is very great, and the machine will accordingly not change its rate of travel suddenly. Therefore, assume a machine flying at 40 miles per hour over the ground in a gentle wind, and suppose that a gust traveling 10 miles an hour faster than

the wind, against which it has been going, strikes it. The machine can not slow down but simply charges into that gust at 40 miles an hour. Consequently, the pressure on the wings is increased and the machine rises exactly as the soaring birds do under similar conditions. But consider the effect of opposite conditions. Assume the machine to have reduced its speed in relation to the earth, so as to get to its proper flying speed in relation to that gust of wind. Presently, it goes right through that gust and into the lull on the other side, just as a boat rides over a wave and falls into the trough between the waves. Now it is flying too slowly for the area of comparative calm that follows the gust; the pressure is decreased and with it the lift, so that the machine drops—if not very high it may strike the ground, as has often been the case. If high, it merely drops until it picks up its normal speed again and increases the pressure accordingly. The sudden drop is very disconcerting and is the cause of numerous accidents, particularly where the machine is not up high enough to permit of falling into one of these "holes in the wind" without coming to earth.

Relative Speed of Wind and Aeroplane. The speed of a machine through the air has little to do with its speed over the ground. The important thing is its speed with relation to the wind against which it is traveling—or rather attempting to travel would be better, as strikingly illustrated by the experience of Johnstone and Hoxsey trying to make headway against a gale of wind at the International Meet at Belmont Park. The wind was blowing 40 to 50 miles an hour, exceeding the speed of which the Wright biplanes were capable. They accordingly simply headed directly into the wind and were blown backward by it, at times remaining perfectly motionless in the air, with regard to the ground, when the wind and the thrust of the propellers equalized each other, gaining a little at each lull, and losing more with each stronger gust, Johnstone traveling more than 40 miles in this manner, while Hoxsey went about two-thirds of that distance before alighting. Hence, it is easy to appreciate that the 40-mile-an-hour machine, which can make that speed in still air, can travel only 20 miles an hour against a 20-mile wind, and can travel 60 miles an hour over the ground with a 20-mile wind.

Assume the machine to be flying in a gusty wind; it is making 40 miles an hour and is in a gust traveling 20 miles an hour. The

biplane is going 60 miles an hour and will accordingly travel through the gust in a short time into slower air, traveling at, say, 10 miles an hour. The machine is then going 60 and the wind only 10 miles, so the machine is going 50 miles an hour faster than the air when it should be going only 40. Consequently, the pressure under the planes increases; the machine rises suddenly till the rush of the extra momentum is expended; and then settles down to its proper speed of 40 miles an hour through the wind, plus the 10-mile-wind speed, which makes 50 miles an hour.

Then the machine runs through the slow wind and overtakes another patch traveling at, say, 20 miles an hour. This time the machine is doing 50 miles an hour, and only 30 an hour more than the wind, which is not enough to keep it in the air, so the whole machine falls until the thrust of the propellers has given it sufficient speed to pick up the extra 10 miles an hour required to attain its critical speed of 40 miles an hour, and by that time it will be going 60 miles an hour over the ground again.

Certain Effects on the Wind. Another important thing to understand is the effect of different obstructions on the wind. A wind blowing against a hillside is bound to blow up along its sides and the wind next to the ground will be compressed by the other wind meeting it, so that when it gets to the top of the hill it will expand, and some of it will blow level along the top of the hill and some of it will continue to rise. An aeroplane falling off the top of such a hill—the bow of a war vessel, as an example—would be lifted quite easily. Again, when a wind strikes a cliff face, the compression may be so great that the wind will rise straight up and curl over, just like a wave, while close to the edge there might be no wind at all. An aeroplane flying in such a wind might well be caught in the "curlover," and dashed to the ground; but if it got as far as the edge, it would be lifted by the up-draft.

Downward drafts also occur and these are dangerous to aeroplanes, because if the pressure suddenly comes from above, as in flying into such a wind, it is difficult to increase the speed quickly enough to counteract this by generating sufficient pressure beneath the planes. Only high speed and a powerful motor would make it possible. The commonest kind of down-draft is formed when the wind blowing over the top of a hill finds the air in the valley at a

lower pressure, and consequently, due to the pressure behind it, swoops down into the valley. Curtiss experienced numerous downdrafts of this kind in his flight from Albany to New York down the Hudson River valley. A less common kind of wind is met with when a cold wind over the sea descends to a cliff edge to replace air that is being drawn away to fill the place of hot air ascending from the heated earth farther inland. This is the phenomenon that causes sea breezes and land breezes alternately at different times of the day.

This uncertain character of the atmosphere—the sudden and extreme variations in the speed of the wind, and frequently in its direction as well, is something for which the aviator has to be constantly on the alert. It is one of the chief reasons why it is safer to fly at a height than comparatively near the ground, for then, unless the aviator has been entirely demoralized by the sudden drop, there is time for him to regain control of the machine before striking the earth.

APR 1 1 1917

EXAMINATION PAPER

THEORY OF AVIATION

PART I

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure you understand the subject.*

1. When was the first power flight by Wright Brothers made?
2. How is the air pressure on a given surface calculated?
3. What is the weight of one cubic foot of air at 32°F. and 30° barometric pressure?
4. What affects the constant of resistance? What value should be given this factor when applied to aeroplanes?
5. Give explanation and diagram of *lift* and *drift*.
6. How is the aerodynamic efficiency of the supporting surface of an aeroplane expressed?
7. What is the angle of incidence? When is this negative?
8. Explain why a perfectly flat plane would not furnish an efficient supporting surface for an aeroplane.
9. Why has a curved plane greater lifting power and what effect upon such a surface does the tangential pressure have?
10. Explain the meaning of the term "aspect ratio." What influence has the value of the aspect ratio upon the design of the aeroplane?
11. What limits the aspect ratio?
12. What is "skin friction" and to what is it analogous?
13. Upon what does the supporting reaction of the air, to a considerable extent, depend?
14. Assume a surface of 5 square feet. Indicate what form this surface should have and how it should be presented to the air to afford the maximum support.
15. How does the center of pressure vary in flight? Is it coincident with the center of gravity?

16. Into what factors may the total resistance encountered by an aeroplane in flight be divided? Give their relative importance.

17. Describe the nature of the atmosphere in motion as shown by Langley's experiments.

18. Briefly mention how the inequalities and irregularities in the atmosphere affect the aviator and what dangers they involve.

19. Is the effect of gravity at all times a disadvantage in flying? How is it utilized by the soaring birds and how taken advantage of by the aviator?

20. Which is more important, the speed of the machine with relation to the earth, or with relation to the wind?

21. Is it possible for an aeroplane to remain stationary with relation to the earth, although its engines are being driven at full speed? If so, explain briefly.

22. Assume that an aeroplane starts from point A to fly to point B, fifty miles distant and due north. A wind of an average speed of 50 miles an hour is blowing from the north. The aeroplane has a maximum speed of 40 miles an hour and its fuel supply permits it to remain aloft for four hours. The conditions remaining the same during that time, where would the aeroplane land at the end of the four hours?

23. Explain briefly why it is safer to fly at a comparatively high level in a gusty wind than close to the ground; also what effect obstructions, such as hills, cause in an otherwise steady wind.

24. Explain how and why the required area of a supporting plane depends upon its speed of travel.

After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.
(Signed)

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